GROWTH AND YIELD RESPONSE OF GARLIC (*Allium sativum* L.) VARIETIES TO NITROGEN FERTILIZER RATES AT GANTAAFESHUM, NORTHERN ETHIOPIA

MSc THESIS

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January, 2015

Haramaya University

GROWTH AND YIELD RESPONSE OF GARLIC (*Allium sativum* L.) VARIETIES TO NITROGEN FERTILIZER RATES AT GANTAAFESHUM, NORTHERN ETHIOPIA

A Thesis Submitted To Postgraduate Program Directorate
(School of Plant Sciences)

HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN PLANT SCIENCE (HORTICULTURE)

By
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January, 2015

Haramaya Ethiopia

HARAMAYA UNIVERSITY

POSTGRADUATE PROGRAM DIRECTORATE

As Thesis Research advisors, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Tadesse Abadi, entitled **“Growth and Yield Response of Garlic (*Allium sativum* L.) Varieties to Nitrogen Fertilizer Rates at Gantaafeshum, Northern Ethiopia”** We recommend that it to be submitted as it fulfills the requirements.

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As members of the Board of Examiners of the MSc. Thesis Open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Tadesse Abadi, and examined the candidate. We recommended that the Thesis be accepted as it fulfills requirements for the Degree of Master of Science in Agriculture (Horticulture).

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DEDICATION

This Thesis manuscript is dedicated for the memory of my mother Adanu Berhe Bitew (1940-2010). She was eager to see every success and stability in my life, Oh! May God would keep her soul in his domicile forever.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for writing it have been dully acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc degree at the Haramaya University and is deposited at the Library of the University to be available to borrowers under the rules and regulations of the Library. I solemnly declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Tadesse Abadi Assemaw, was born at Alamata town, which is located in the Southern part of Tigray Region State, Northern Ethiopia, on 01 May 1978. He attended elementary education at Edget Fana Elementary School from 1984 to 1991 and junior and secondary education at Tadagiwa Ethiopia Senior Secondary School (TESSS) from 1992 to 1997, respectively.

He joined Ambo College of Agriculture (now Ambo University) to study for a Diploma in General Agriculture in 1999. Soon after he was graduated from Ambo College of Agriculture (ACA), he was employed by Raya Valley Integrated Agricultural Development Project (RVIADP) in 2000 and served as supervisor for about two years and then left the project, and was employed by Tigray Agricultural Research Institute (TARI) as technical assistant.

The institute gave him a chance to upgrade his qualification status to B.Sc. level. For this purpose, he joined Mekelle University in 2003 and graduated in 2007 from Department of Dry Land Crop and Horticultural Science (DCHS) in horticultural program. Since then he has been working in different research positions and as team leader.

In September 2013, he joined Haramaya University to pursue his MSc degree in Plant Sciences majoring in Horticulture.

ACKNOWLEDGMENTS

I would like to acknowledge with a great gratification for all those who directly or indirectly assisted me and participated in giving constructive ideas and suggestions during the study period of post graduate. I would express my gratitude with sincere appreciation to my Major advisor Dr. Wassu Mohammed (Haramaya University) and Co-advisor Dr. Gebremedhin Woldewahid (LIVES-ILRI Project Coordinator in Tigray) for their genuine desire and invaluable guidance based on their academic and professional expertise as well as critical review of the thesis manuscript.

I am greatly indebted to the Tigray Agricultural Research Institute (TARI) for providing me opportunity of post graduate scholarship and also the privilege undertake thesis research project by the International Livestock Research Institute (ILRI)-Livestock and Irrigation Value chain for Ethiopian Society (LIVES) project for financial support of thesis research. I also thank Haramaya University (HU), Department of Plant Science for creating smooth and healthy environment in teaching and learning process during my stay in the compass. I would express my thanks to Mr. Desta Fikadu and Dr. Getachew Tabor from Debrezeit Agricultural Research Center (DZARC) for their opinion and provision of improved garlic planting materials. The deepest acknowledgement goes to Mekelle Agricultural Research Center (MARC) staff members for their unreserved facilitation and all possible support from beginning to the final field and laboratory works.

I would like also to appreciate and thank to Mr. Hailemariam Araya (Village Administrator), Mr. Tedros Adiaumer (Irrigation Development Agent), Mr. Gebru Birhane and his son Gezae Gebru (Farmers) for their providing me of the land, data collection, for the day-to-day management of the field experiment in Guahgot village-Gantaafeshum district respectively. Similarly, I would also thanks to Mekelle soil laboratory research center for the permission to use their soil and plant analysis laboratory.

At Last but not the least, I would like express my deepest gratitude to my beloved wife Atsede Michael, my elder daughter Arsema Tadesse and younger daughter Yididiya Tadesse, my mother Zenebu Endris for their prayers, love and affection which encouraged me to focus on finalizing the study.

ACRONYMS AND ABBREVIATIONS

ACA	Ambo college of agriculture
ATA	Ethiopian agricultural transformation agency
ANOVA	Analysis of variance
BAU	Bangladesh agricultural university
CEC	Cation exchange capacity
CIMMYT	Center of international maize and wheat improvement
CSA	Central statistics agency
DAP	Di-ammonium phosphate
DCHS	Department of crop and horticultural science
DZARC	Debrezeit agricultural research center
EIAR	Ethiopian institute of agricultural research
FAO	Food and agricultural organization
FAOSTAT	Food and agricultural organization statistics
ILRI	International livestock research institute
LIVES	Livestock and irrigation value chain for Ethiopian society
MACB	Ministry of agriculture and cooperatives of Bangkok
MARC	Mekelle agricultural research center
MoARD	Ministry of agriculture and rural development
NMA	National meteorological agency
OARI	Organization of agricultural research institute
SM	Sub-moist mid-high lands
TARI	Tigray agricultural research institute
TSP	Triple super phosphate
TSS	Total soluble solids

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ABSTRACT

Garlic (Allium sativum L.) is one of the most important vegetable crops produced in Tigray region; however, farmers are producing the crop from the available cultivars without or with very low rates of nitrogen fertilizer. The cultivars produced in the region were not evaluated in comparison to improved varieties to the response of nitrogen fertilizer. Therefore, this experiment was conducted during 2014/2015 in Gantaafeshum district in Tigray region with objectives of assessing the effect of nitrogen rates on yield and yield related traits of garlic cultivars and thereby identifying adaptable and high yielding cultivars with higher market demand. Seven garlic cultivars (three improved, three locally introduced and one local) and four N fertilizer rates (0, 41, 82, 123 kg N ha^{-1}) were arranged as 7 x 4 factorial treatments and laid out as a randomized complete block design with three replications. All yield and yield related traits were significantly influenced by the interaction of cultivar and nitrogen fertilizer except leaf length (cm), leaf number per plant, bulb length (cm) and sizes of bulbs and cloves of different categories that were significantly influenced either by both cultivar and nitrogen or one of these. The highest total yield was obtained from the cultivar Bora 1 (12.61 t ha^{-1}) at the rate of 82 kg N ha^{-1} but the yield decreased to 12.27t ha^{-1} as the nitrogen level increased to 123 kg N ha^{-1}. The lowest yield was recorded from the local cultivar Guahgot (5.31 t ha^{-1}) without N fertilizer application. The quality was determined based on number of marketable bulbs and weight of cloves.Bora-1 had 44.44 and 20% of bulbs categorized under medium and large categories, respectively. This cultivar had also the highest proportion of marketable cloves categorized under medium (27.10%) and large (33.80%) clove categories. The cost benefit analysis indicated that cultivar Felegdaero followed by Bora 1 both at 41kg N ha^{-1} rates had maximum marginal economic return of 148.24 and 135.84, respectively. Therefore, it is possible to suggest the advantage of growing cultivar Bora-1 at 82 kg N ha^{-1} followed by Tsedey and Felegdaero varieties both in combination of 123 kg N ha^{-1} at Guahgot, Gantaafeshum district and in other areas having similar agro-ecology.

Key words: Bulb yield, garlic variety, local cultivar and nitrogen

1. INTRODUCTION

Garlic (*Allium sativum* L.) belongs to Alliaceae family (Allen, 2009). The origin of garlic is thought to be in Central Asia (India, Afghanistan, West China, Russia) and spread to other parts of the world through trade and colonization (Tindal, 1986). Garlic has been used in China and India for more than 5000 years, and Egypt since 2000 B.C. (Kamenetsky and Rabinowitch, 2001). Garlic is the most important *Allium* crop and ranks second next to onion in the world (Voigt, 2004).

With respect to its production and economic value, garlic is one of the main *Allium* vegetable crops in the world and used as a seasoning in many foods throughout the globe. The oil of garlic is volatile and has sulfur combining compounds which is responsible for strong odor, its unique flavor and pungency as well as for healthful benefits (Salomon, 2002). Garlic is a basic flavoring in many types of dishes ranging from vegetable soup, meat, salad, tomato combination, spaghetti, sausages and pickles (Brewster, 1994). Similar to green onions, it is eaten as green and blenched tops in different ways as fresh and cooked as well as immature bulb consumption is common especially in tropics (Rabinowitch and Brewster, 1990). Bread and butter obtained from garlic have many uses in homes and restaurant cooking and food preparations (Nonnecke, 1989). Garlic has also medicinal value which is well recognized in the control and treatment of hypertension, worms, germs, bacterial and fungal diseases, diabetes, cancer, ulcer, rheumatism etc. (Kilgori *et al*., 2007(b); Samavatean *et al.*, 2011). Many people perceived and appreciated garlic for its many medicinal attributes (Rabinowitch and Currah, 2002).

The plant can perform best when planted on well drained soils. It is better to plant on flat beds; but on heavy soils, which are poorly drained during the rains; it is advisable to plant on the ridges. To obtain good yield, producers should give attention to select a land which has high fertility and apply considerable quantities of manure or fertilizers. Garlic production requires a growing period of 4.5-6 months and the amount of rainfall ranges between 600 mm to 700 mm during its production season. The optimum temperature for garlic growing lies between 12 °C and 24 °C. Garlic withstands moderate frost. Garlic production spread throughout the country and has been cultivated under irrigated as well as rain fed conditions, mainly in the mid and highlands of Ethiopia (Lemma and Hearth, 1994).

Garlic is one of the most important vegetable crops in Ethiopia and is used as ingredient of local stew ‘wot’ and has also a tremendous use in the formulation of local medicines. According to CSA (2012), in Ethiopia, garlic was cultivated on 13278.55 hectares of land and above 1.2 million quintal of yield was harvested during 2011/12 crop season. The average yield per hectare was 9.34 ton. Garlic is one of the most important bulb crops produced by small and commercial growers for both local use and export (Metasebia and Shimelis, 1998). As a cash crop, it is used to earn foreign currency by exporting to Europe, the Middle East, Africa countries and USA (Kilgori *et al.,* 2007). At off season the same quantity of garlic is usually sold at twice or three times the value of onion (Getachew and Asfaw, 2000).

In Tigray, producing and marketing high value vegetable crops are intensifying throughout the region. Different vegetables and spices have been introduced and cultivated mostly in the lowlands or flood plains where source of water and soil fertility is relatively higher. Garlic is one of the high value vegetable crops produced during the cold season, in rotation with pulses that have contributed in breaking the life cycle of pest problems and improve soil fertility (Gebremedhin *et al.,* 2010). In the year 2011/2012 production season, the area covered by garlic production was about 616.10 ha; the total production obtained from this hectare was 8891.8 tones (CSA, 2012).

In spite of its importance (increasing of garlic production and productivity), garlic yield is low in many parts of the world, due to genetic and environmental factors affecting its yield and yield related traits (Nonnecke, 1989). In many garlic producing areas, lack of available nutrients is frequently the limiting factor next to soil water, because the uptake and liberation of N, P and S from soil organic matter depends upon availability of water (FAO, 2003). The other production constraints of garlic include lack of improved varieties resistant to major diseases and insects (Getachew and Asfaw, 2000). To overcome such production problems, great effort should have to be made in the selection and breeding of high yielding cultivars and the development of cultural techniques (Rabinowitch and Brewster, 1990.

The most constraint of garlic production and productivity of the country in general and of the study area in particular is lack of improved variety (ies) in required quality and quantity. Consequently, farmers are restricted to use garlic landraces inferior in yield, prone to most of the diseases and insects with traditional agronomic practices. However, it is supposed that not all local cultivars are inferior in yield and quality. But less attention has been given to evaluate the local cultivars along with the improved varieties. Mostly farmers in Tigray region are using very low fertilizer rate below blanket recommendation. Because, it is not known the optimum rate of N and apply very small amount which could not have significant function for the crop production. Therefore, the low yield in the region is expected to be the results of lack of improved and adopted garlic varieties as well as the low N-fertilizer rates application. To overcome this problem, it is necessary to introduce improved garlic varieties and agronomic practices in the area which requires testing and identifying of suitable technologies before making recommendation.

A study in the Central Ethiopia indicated that application of 92 kg N ha^{-1}, 40 kg P ha^{-1}, and 30 kg S ha^{-1} was appropriate to attain maximum quality of the crop for enhanced household income (Diriba *et al*., 2013). It was also reported that garlic bulbs supplied with N, P and S improve bulb quality and nutrient contents did not significantly respond to highest level of phosphorus for bulb yield. Nitrogen and sulphur application showed a direct and positive effect on pungency and total soluble sugar (TSS) content. This showed that the importance conducting research focusing on N rates to increase yield which is partly the extension of the previous study. On the other hand, it is necessary to test different varieties and farmers cultivars with different N rates to identify variety (ies) and/or local cultivar(s) to attain maximum garlic yield potential for the specific agro-ecology. This is because that the varieties and agronomic practices recommended elsewhere may not perform in the new areas due to agro-ecology and genotype by environment interaction differences. Therefore, this study was initiated with the general objective of selecting high yielding and adaptable garlic cultivars with optimum nitrogen level to be applied in the study area.

Specific Objectives:

1. To identify adaptable and high yielding garlic varieties/cultivars with higher market demand for the study area
2. To elucidate response of garlic varieties/cultivars to nitrogen rates on growth, yield and yield components of garlic

2. LITRATURE REVIEW

2.1. General Description

Botanically, garlic belongs to the genus *Allium* family Alliaceae, which includes important vegetable crop such as onion (*Allium cepa*), leek (*A. ameloprisum*) and shallots (*A. asacloncum*). Garlic is a diploid species (2n = 2x = 16) of obligated apomixis and propagated vegetatively (Figliuolo *et al*., 2001; Ipek *et al*., 2003; 2005).

Garlic is propagated asexually, but shows a high morphological diversity among cultivars. These cultivars have a wide range of adaptation to different environments. Like onion, garlic plants have thin tape shaped leaves about 30 cm long. Roots reach up to 50 cm depth or little more. Heads or bulbs are white skinned, divided into sections called cloves. Each head could have from 6 to 12 cloves, which are covered with a white or reddish papery layer or “skin” (Hector *et al*., 2012).

Sexual propagation in garlic is expected to facilitate the exchange of genetic traits from one genotype to another and to improve garlic cultivars through classical breeding (Kamenetsky *et al.*, 2004). Garlic does not produce true seed but it is propagated by planting cloves. Each bulb usually contains a dozen or more cloves and planted separately. Select only larger outer cloves of the best garlic bulbs for planting because larger cloves yield larger size and mature bulbs at harvest.

Do not divide the bulb until ready to plant; early separation decreases yields. Select “seed bulbs” that are large, smooth, fresh, and free from disease. To plant garlic properly, dig a hole or trench, place the unpeeled clove gently into the hole with the pointed side up (the scar [stem] end down) and cover the clove with soil. Setting the cloves in an upright position ensures a straight neck (McLaurin, 2012).

2.2. Ecology Requirements and Production of Garlic

The ecological requirements of garlic is with a reasonably mild winter regions which have some rainfall followed by a sunny dry summer, with good for maturity and harvesting of the bulbs are ideal for garlic production (Brewster, 1994). Very high or Excessive humidity and rainfall are unfavorable to vegetative growth, bulb formation and reduced production. The garlic plant is easily stressed by insufficient moisture and water logging during its growing period (Rubatzky and Yamaguchi, 1997). To attain the maximum yield, the top upper surface should be moist and maintained close to field capacity for most of the growing season (Brewster, 1994). The geographical areas providing mean monthly temperature ranging from 12-24 ^{0}C is best for garlic growing. High temperature is required for optimum bulb development but cooler condition in early stages favor vegetative growth. Elevations less than 2000 m a s l is not suitable for garlic growth and production (Nonnecke, 1989).

Garlic has a wide area of adaptation and cultivation throughout the world. On global basis, the leading producers are China, Korea, Thailand, Spain, Egypt and India. The productivity of garlic in many parts of the world is low due to genetic and environmental factors affecting its yield and yield related traits (Nonnecke, 1989). The area covered by garlic exceeds 1,142,000 ha and its average productivity is estimated to be 12t ha^{-1} in the world (FAO, 2003).

World production of garlic is ranked 14th among vegetables with a total of 14.5 million ton (Trejo, 2006). In Mexico, its consumption is about 400 g per capita (Chavez, 2008), and the production is considered low as compared to other countries such as China (80 % world production), India, Korea and (20 %) the rest of the world (FAOSTAT, 2011).

As indicated Anonymous, (2004) the term ‘seed’ in the garlic refers to individual cloves separated from a bulb. The ‘seed’ needed per hectare are very variable as the cloves of different species vary greatly in size. When using your own planting stock, harvest the planting stock bulbs later than your main crop, as harvesting very mature bulbs increases the ease of clove separation, otherwise when out it will produce smaller bulbs. The upper 15-20 cm of the soil surface should be always moist, but not wet, because most of the root system will be grown in this depth (Trejo, 2006).

Yield and quality will vary with climate, region, altitude, soil and pH, cultural practices, and the variety of garlic. The term "biological elasticity" describes garlic's ability to acclimate to these factors over time. No one practice is best suited for every situation. It is advisable to conversation with local growers who have experience growing garlic and experiment with different cultural practices and varieties to discover the best combination for your operation (Siktberg *et al*., 2006). Lighter soils will need more frequent water applications, but less water applied per application. Water stress during the growing season can cause bulbs to be smaller and is thought to also cause a multiple stem disorder (Anonymous, 2004).

2.3. Growth and Development

Garlic is a cool season plant; it makes all vitality and leaf growth while the temperatures are cool and the day is short. As the temperature becomes warm and the day is lengthen, the plant stops making leaves and begins to form bulbs. Cloves or young plants exposed to temperatures of between 0 ^{0}C and 10 ^{0}C for one to two months hastens subsequent bulbing under long days (Moore and Gough, 2010).

A study in the Netherlands conducted by Messiaen and Rouamba (2004) during the life cycle of plant under go successive stages of growth and development, the dormancy of mature cloves, induced by the temperature of 25-30 ^{0}C is eliminated most quickly at 6-7 ^{0}C vegetative growth is optimal at 18-20 ^{0}C. When 12-14 leaves have been produced, bulb swelling is induced at temperature below 20 ^{0}C. There is considerable physiological variability amongst garlic cultivars. The total growing period varies from 4 months to about 9 months.

According to McLaurin, (2012) the matured garlic cloves planted in the fall go through a dormant period. Garlic cloves require a period of 6-8 weeks of cool weather after planting (below 4.4 ^{O}C to undergo vernalization inducement to bulb) by low winter temperatures.

During the fall and winter in Georgia, cloves will develop their root systems and initiate some top growth. The clove will swell considerably, forming a globular bulb with many fine roots. A pair of intertwined leaves will emerge from the terminal end of the bulb and will eventually break through the soil, depending on the weather and location. Leaf development will accelerate with flat, dark green leaves on stems reaching a height of 30 cm or more. Proper bulbing is a function of adequate growth, vernalization, and subsequent growth under longer days. As temperatures rise and day length increases, bulb formation begins.

Results show the following development stages in garlic: Sprouting: from sowing to 20-30 days, adventitious roots, leaf emergence and total soluble carbohydrate assimilation in seed cloves are observed. Shoot growth: from the end of sprouting until 140 days after sowing. Translocation of photosynthesis to the bulb begins afterwards. Bulb growth: during the inductive stage, from sprouting, no increases in dry weight in total soluble carbohydrates can be observed up to 90 days Ledesma et al., (nd.).

For proper growth, garlic needs a period of cold followed by a period of light and heat. Although garlic requires low temperatures in preparation for bulb development, increased day length and heat are necessary for bulbs to begin forming (Siktberg *et al*., 2006). Garlic is a species of vegetative propagation, showing high morphological diversity. Besides, its clones have specific adaptations to different agro-climatic regions (Paredes *et al.*, 2007). Garlic shows wide morphological and agronomic variations in characteristics such as color and size of the bulb, plant height, number and size of the cloves, days to harvesting, resistance to storage capacity, dormancy and adaptation to agro-climatic conditions (Figliuolo *et al*., 2001).

Leaves will begin to turn brown and tops will fall, indicating maturity. Stop irrigation at this time to avoid bulb discoloration and bulb rots. To ensure bulbs are fully mature, remove the top layer of soil over the top of a few bulbs and check bulbs to make sure they are fully differentiated (division of bulb into distinct cloves). Harvest the garlic when 1/3 to 1/2 of the leaves have died back in this manner (McLaurin, 2012).

2.4. Irrigation and Field Management

Most of the time garlic really likes moist soil. Watering regularly in the fall during germination is essential. In dry climates, watering is also important. Do not let the upper surface of soil turn to dust. Try the old farmer's test of clumping a bit of soil in your fist. If the clump stays together upon releasing your fingers, it is wet enough. If not, water. During the last four weeks, when the bulbs are finishing off, and the wrappers are drying out, too much water is not good. You can create a mold or fungus problem. In drier climates some people like to heavily irrigate at the pre-planting phase to help build a deep soil moisture reserve (FAO, 2007).

Garlic requires between 2.5 cm and 5 cm of water per week. Like nitrogen, water will have its greatest effect on yield prior to bulbing. Adequate moisture is still needed after bulbing, but irrigation should be stopped at least two weeks prior to the expected harvest date. Late-season irrigation tends to stain the skins and reduce quality (Goldy, 2000).

As Hickey (2012) conducted research in Australian, for optimum yields, water stress should be avoided in garlic crops prior to the first signs of maturity. The fibrous root system is confined to the top of soil and sufficient water should be applied to wet the soil to this depth. Cease irrigation when the first signs of maturity are evident (tops yellowing or necks softening). If cultivation is necessary for weed control or for water infiltration, keep it shallow to avoid root pruning. A knife may be used. Weeds that have emerged in the row must be removed by hand hoeing (Hickey, 2012).

2.5. Composition and Uses

According to Volk and Stern, (2009) bulb elemental analysis in Northern Colorado, bulbs was significantly different was performed for the elements on freeze-boron, magnesium, phosphorus, potassium, and nitrate-nitrogen. They also reported that Nevada bulbs were high in potassium, sulfur, and zinc and were high in sodium. It has higher nutritive value than other bulb crops in addition to containing antibiotics like garlicin and allistatin (Maly *et al*., 1998).

But the growth and yield of garlic is influenced by different nutrition management and other factors during their production in field (Diriba *et al*., 2013).

Its flavor is due to a group of sulfur containing compounds and lachrymatory effect of garlic is due to the high proportion of 2-PECSCO (2-propenyl L-cysteine sulphoxide) content. The bulb contains about 1.4% of the fresh weight as alliin (Brewster, 1994). Garlic is rich in sugar, protein, fat, calcium, potassium, phosphorus, sulfur, iodine, fiber and silcon, in addition to vitamins. Its pungent flavor makes it used mainly as a spice, seasoning and flavoring for food stuff involving both green tops and bulbs (Kilgori *et al*, 2007). Moreover, it contains considerable amounts of Ca, P and K and its leaves are sources of protein, vitamin A and C (Mahmood, 2000; Samavatean *et al*., 2011).

As Hector *et al*., 2012 also reported that bulbs are consumed fresh, totally or partially dried, and pickled. Although the bulb consumption is more common, tender shoots sometimes are a delicatessen for sophisticated cuisine. These shoots may be prepared like asparagus. Each clove is capable to develop a new plant, since they have an apical shoot bud that can elongate even though they are not sown. This shoot is apparent after three months of the harvest, depending on the genotype and conservation conditions. These stems produce a strong odor from two compounds: alliin and diallylsulfide.

2.6. Garlic Production and Productivity in Ethiopia

In Ethiopia, Garlic is one of the important bulb crops grown and used as a spice or a condiment throughout the country. It is mainly used for flavoring and seasoning vegetables in different dishes. It also has many medicinal properties (Abreham *et al.*, 2014).

Small growers in the highlands are growing garlic traditionally but due to faulty cultural practices, yields are generally low. The yield in large-scale production with irrigation is expected to be about 10 tons per hectare (CVR, 2009). According to the central statistical agency (CSA) of Ethiopia, 2011 the number of holders practicing garlic farming is considered to be 1,411,151 farmers which are much less than that of grains or cereals crops. In the same year the area under garlic production was estimated 10,690.41hectars and the production obtained from these hectares were about 1,284,409.36 quintals as well as the average production predicted 120.15 quintal yield per hectare.

Garlic is adapted to cool climates and should not generally be planted at altitude below 2000 m. a. s. l. Amount of rainfall during the growing period (4 to 6 months) should be 600 mm to 700 mm. The optimum temperature for growing garlic lies between 12°C and 24°C. Garlic withstands moderate frost on well-drained soils, rain fed crops may be planted on flat beds; but on heavy soils, which are poorly drained during the rains; it is advisable to plant on ridges as for irrigated crops. It is essential to select land with high fertility or to apply considerable quantities of manure or fertilizers to obtain good yields (CVR, 2009).

Under the comparison of countries in garlic production, next to ten top garlic producers, China, India, South Korea, Egypt, Russia, Bangladesh, Burma, Uzbekistan, Ukraine, United states. Ethiopia has placed number 12 in the world ranking and world share of Ethiopia in garlic exporting was very small amount only 0.7 % (FAOSTAT, 2013).

2.7. Variety Development

The different garlic species are classified in four groups: *longicuspis*, *ophioscorodon*, *sativum*, *subtropical* and the *pekinense* sub-group. The *longicuspis* group is considered the oldest and it is postulated to be the original group. The *ophioscorodon* group is distributed in Central Asia, the *sativum* group in the Mediterranean zone and the *subtropical* in the south and southeast of Asia. Finally, the *pekinense* subgroup comes from the east of Asia (Maab and Klaas, 1995).

To develop specifically adapted and high yielding varieties in such variable rain fed environments like in Tigray, joint experimentation has to be initiated through farmers experimentation and own innovation (Fetien and Bjornstad, 2008). As Rahim, 2011 explain that selection of improved genotypes, development of appropriate management practices, and production of bulb and quality seeds are important to reduce the existing wide gap between consumption and production. Collect, characterize (morphological and molecular) and conserve local and exotic germplasms of garlic for developing variety/varieties.

Thirty-three germplasms of garlic were collected from domestic and exotic sources. Yield performances of these collected germplasms were assessed through field testing. Management practices for bulb and seed production were also assessed through field trials. After initial screening, 25 germplasms of garlic were selected and conserved (Rahim, 2011).

The effectiveness of selection depends on the amount of variability present in the genetic material for yield and yield related characters. The majority of traits important to crop productivity are controlled by the combined effects of a number of genes that influence the trait; each has a similar small influence (Pike, 1986). The Mexican genotypes have a wide variation on clove size and number that reflects good genetic pool for breeding through individual selection of plants. Some other characteristics are qualitative that may have positive impact for worldwide market demands. For example, the late cultivars have the longest storage life (Hector *et al*., 2012).

Garlic cultivated in rural farms of South Italy is often a heterogeneous clone population, which can comprise different cytotypes. Significant differences in yield were observed within and between ploidy levels. Discriminant analysis did show that four characters (leaf basal width, total number of leaves, clove diameter and neck height) were able to correctly discriminate all germplasm accessions **(**Figliuolo *et al*., 2006).

According to Hector *et al*. (2012) described that higher differences of bulb diameter were found among varieties. Plants showing a smaller number of cloves per bulb appeared to have greater clove weights. 'Chino' and 'Coreano' varieties also showed a good clove weight performance. However, they are more susceptible to diseases and they require more time for bulb formation. Varieties with greater bulb weights appeared to be taller than those with smaller bulb weights.

Varieties of garlic can be harvested at either 150 (early cycle), 180 (intermediate cycle) or 210 (late cycle) days after planting. Late cycle varieties showed greater bulb and clove weights. Greatest bulb weight varieties showed more than 75% greater bulb weight than lowest bulb weight varieties had a better tolerance to environmental conditions, their bulbs had fewer cloves (10-12), and their bulb and clove weights were favorably compared with those of commercial varieties in California (Hector *et al*. (2012).

2.8. The Role of Variety on Garlic Yield and Yield Components

The variety must be selected from a list of recommended or local varieties. Apart from its adaptation, the variety should have high yield potential, tolerance to biotic and abiotic stresses, good marketability and high consumer preferences. Unless the variety meets the requirements of farmers and consumers, it is less likely to be widely adopted and therefore, the demand for seed cannot be addressed (Bishaw *et al*., 2008).

The character of yield reflects the performance of all plant components and might be considered as the final result of many others i.e. every plant contains an inherent physiological production capacity that operates on energy required for normal plant performance though all accessions do not have the same inherent physiological capacity to yield. Breeders commonly find yield to be a very complex array of plant component interactions and by the manipulation of these genetic systems yield is improved as the result of plant efficiency improvement (Welsh, 1981).

The yield performances of twenty five garlic germplasms were evaluated and gave quit satisfactory, yielding 6.5-9.4 t/ha in Bangladesh agricultural university (BAU). Garlic germplasm G-49 produced the highest yield (9.4 t/ha) followed by G-53 (7.9 t/ha) and G-27 (7.6 t/ha), the National Seed Board registered the G-49 garlic germplasm as garlic-3 variety for mass production. Allicin content of local germplasm (G-13) is quite high (2.4 mg/ml) (Rahim, 2011).

2.9. Function of Nitrogen in Growth and Development

Farmers strive to produce high yield and good quality garlic both for consumption and economic value but soil fertility depletion is among the major obstructions to sustained garlic production, especially in the less developed countries, because of limited application of suitable rate, type and sources of fertilizers (Diriba *et al.*, 2013).

Nitrogen has been identified as being the most limiting nutrient in plant growth. Plants absorb nitrogen in the cation form (NH_4^+) or the anionic form (NO_3^-). Plants obtain readily available N forms from different sources. The major forms include: biological nitrogen fixation by soil microorganisms, mineralization of organic N, industrial fixation of nitrogen gas and fixation as oxides of nitrogen by atmospheric electrical discharge. Similarly, mineralization of organic nitrogen to inorganic forms depends on temperature, level of soil moisture and supply of oxygen (Tisdale *et al.*, 1995; Miller and Donanue, 1995).

Nitrogen is necessary and important element for increasing the yield and quality of vegetables such as garlic (Gulser, 2005). As increased the level of N, increased the growth trend of the number of leaves, leaf length and plant body that garlic has a high nitrogen requirement, particularly in the early stages of growth. The highest yield was obtained in high N application of 300 kg N ha^{-1} (Sardi and Timer, 2005).

Availability of nitrogen is a prime importance for growing plants as it is a major and indispensable source of protein and nucleic acid molecules. It is also an integral part of chlorophyll molecules, which are responsible for photosynthesis. It is well known that the use of fertilizer helps in production and is a somewhat quick method for achieving maximum yields (Naruka and Dhaka, 2001). Manure is a good supplier of organic matter, but usually a low and slow supplier of nutrients, as it releases over a year. If you are using manure some of the above mentioned nutrients will only become available over time (Anonymous, 2004).

The available nitrogen form can be made unavailable or lost via plant uptake, denitrification, volatilization, leaching, and ammonium fixation (Tisdale *et al.*, 1995). The loss of available nitrogen through natural processes is believed to surpass the gain (Miller and Donahue, 1995; Tisdale *et al*., 1995). This fact has made fertilizer management is an important aspect of crop production practices (Kleinkopf *et al*., 1987). Consequently, nitrogen is applied relatively in large quantities all over the world (Sanchez, 1976; Miller and Donanue, 1995). The deficiency of nitrogen has an overriding control on plant growth and dominates the effect of other plant nutrients (Miller and Donanue, 1995; Tisdale *et al*., 1995).

The nitrogen fertilizer levels demonstrated on Kermani garlic heap progress of 60 to 180 kg urea, increased length and number of leaves of garlic. At highest application of urea, the highest yield was recorded (Khodabakhshzadeh, 2001; Maryam *et al*. 2012).The application of increasing rates of nitrogen had significant effect on fresh bulb yields. It was observed that the combined increasing levels of nitrogen from 0 to 120 kg ha^{-1} resulted in significant in fresh bulb yield; however further increase to 240 kg N ha^{-1} reduced the yield (Kilgori *et al*., 2007).

The morphological characters like plant height, neck diameter and leaf area index, and the concentrations of N, P, K and S nutrients, and their uptake of garlic plant were significantly influenced by the applications of different compound fertilizers, season and soil types at different growth stages (Diriba *et al*., 2013). Kumar and Rao (1992) and Panda *et al*. (1995) indicated that increasing N and P uptake with increasing N and P fertilizer applications to the soil as a result of improved availability and uptake through increased root growth and effective absorption.

Based on Tyler *et al.*, (1988) five-year study of garlic mineral nutrition has shown that responses of the California Early and California Late varieties to fertilizer application are moderate. Addition 113.5 to 127 kg of nitrogen per ha should be sufficient for garlic. Application of nitrogen fertilizer increased growth and yield parameters over control. The application of 200 kg N ha^{-1} significantly increased the growth attributes like plant height in cm and neck thickness, bulb diameter, number of cloves per bulb, fresh weight of cloves, dry weight of cloves, fresh weight of bulb, dry weight of bulb and bulb yield qt ha^{-1} (165.18) in comparison to 50 kg N ha^{-1} and 100 kg N ha^{-1}. However, no significant difference was recorded between 200 kg N ha^{-1} and 150 kg N ha^{-1} (Farooqui *et al*, 2009).

The different growth parameters improved with increasing application rate of N up to 120 kg N. Also, bulb fresh weight increased significantly with application 120 kg N than 80 kg N by 17.6 % and 21.5 % in the two growing seasons respectively (ElHifny, 2010). As a result of comparison, increasing the amount of fertilizer to 200 kg N ha^{-1} increase highest (16,620 kg ha^{-1}) yield, and the lowest yield loss (11,530 kg ha^{-1}) was obtained with the application of 300 kg N ha^{-1} (Khodabakhshzadeh, 2001). In line to this finding , there was also reported with increasing amounts of urea up to 200 kg ha^{-1}, the yield and quality of garlic showed an increasing trend than 225 kg N ha^{-1} (Gaviola and Lipinski, 2008; Dos and Mohanty, 2001). Buwalda (1986) also reported on the treatment of 120 kg N ha^{-1} cause yield up to 200 qt ha$^{-1.}$

Comparison of quantitative traits showed ammonium sulfate fertilizer was more effective in weight single clove. This can be attributed to a number of clove since urea was also significantly increased the number of clove, and are smaller clove by increasing the amount of fertilizer to 200 kg N ha^{-1} single clove weight gain and then decreased with increasing fertilizer (Huchette *et al*., 2004). Correlation between some quantitative traits of garlic showed the positive and significant correlation with yield and leaf length. Between performance and bulb diameter and length, diameter and weight clove showed positive correlation observed at 1%. Leaf length, bulb diameter and length, and the mean number clove negative clove and significant bulb weight and number of leaves per plant were showed significant positive correlations (Maryam *et al*., 2012).

The quantity of nutrients to be applied depends on the yield potential of the cultivar, the level of available nutrients in the soil, and growing conditions (Marschner, 1995). Similarly, Selections of the best variety with their proper rate of fertilizer rate are very important factors to increase productivity and marketability of garlic (Abreham *et al.*, 2014; Shaheen *et al.*, 2007). The effect of N fertilizer levels on the performance of different onion varieties suggested that N levels significantly enhanced plant height, produced the bulbs of greatest marketable yield, total bulb yield (Tibebu Simon *et al.*, 2014).

According to Abreham *et al.,* (2014) the interaction of variety, nitrogen and phosphorus were increased the total bulb yield. The same manner the nitrogen and phosphorus fertilizer application alone as well as across interaction of the varieties had increased on total bulb yield due to varieties.

3. MATERIALS AND METHODS

3.1. Description of the Study Site

Gantaafeshum is the potential garlic growing district located Eastern Zone of Tigray region, Northern part of Ethiopia. It is one of the nine districts in the eastern zone of the region and 120 km to the north from the capital city of Tigray, Mekelle (TLZR, 2014). The experiment was conducted at Guahgot Farmers Training Center (FTC) in the Gantaafeshum district at 2014/2015 growing season, which was planted at off season with irrigation. The testing site is located at 14º 16' 57" N and 39º 46' 97" E latitude and longitude with altitude of 2444 m. a. s. l. (GPS Reading). According to FAO (2005) area has the mean annual rainfall of 552 mm. It has mono-modal rainfall which extended from June to September with peak rainy month in August. The mean annual minimum and maximum temperatures are 7.7 ^{0}C and 24 ^{0}C, respectively. The coldest month is December while the warmest month is May. According to Tigray Bureau of Agriculture and Rural Development (BoARD, 2009) the soil type for garlic growing area of Gantaafeshum district is Cambisols.

3.2. Experimental Materials, Treatments and Design

Three improved varieties (Bishoftu Nech, Tsedey 92 and Kuriftu) released by DebreZeit Agricultural Research Center, under Ethiopia Institute of Agriculture Research (DZARC/EIAR), three local cultivars (Felegdaero, Bora-1 and Bora-2) which were found elsewhere in the region, that introduced to the study area and one local garlic cultivar (Guahgot) was produced locally around the experimental site. A total of seven cultivars were used as testing materials. There was a Farmers' association organized at Adishahu district in Bora village to produce garlic seed, the two local cultivars (Bora-1 and Bora-2) were produced, maintained and used as garlic seed production. The description of the planting materials is presented in Table 1.

Table 1. Description of garlic cultivar used for the experiment during 2014/15 at Guahgot (FTC) in the Gantaafeshum district of Tigray region

Cultivar	Year of release	Breeder/Maintainer
Bishoftu Nech (W-014)	1999	DzARC/EIAR
Tsedey 92 (G-493)	1999	DzARC/EIAR
Kuriftu	2010	DzARC/EIAR
Felegdaero	Farmers maintained for many years	Farmers around Mekelle
Bora-1	Farmers maintained for many years	Farmers around Bora
Bora- 2	Farmers maintained for many years	Farmers around Bora
Guahgot local	Farmers maintained for many years	Farmers around Guahgot

Four nitrogen fertilizer rates viz., 0, 41, 82 and 123 kg N ha^{-1} were used. The rates were derived from blanket recommendation rate of urea (100 kg ha^{-1}) and di-ammonium phosphate (DAP) (200 kg ha^{-1}). Urea contains 46% N and DAP contains both 18% N and 46% P_2O_5. Urea was applied as split application. It was applied as one-third during planting, one-third at active vegetative growth (three weeks after plant emergence) and the rest one-third six weeks after plant emergence just before bulbing as side dressing. However, 200 kg triple super phosphate (TSP) (46 % P_2O_5) per hectare was applied at the time of planting uniformly in all treatments. The experiment was arranged in 7 x 4 factorial combinations (28 treatments) which were laid out in randomized complete block design (RCBD) with three replications.

3.3. Management of the Experimental Field

The land was ploughed and leveled properly before planting. The planting materials (cloves) were planted with the tip in upright position and the basal part of the clove down. The spacing between blocks, plots, rows and plants were 1m, 0.75m, 0.30m and 0.10m in single rows, respectively. The spacing between rows and plants which was proposed to be used in this experiment was adopted from the previous recommendation for the variety 'Tsedey' which was planted on a ridge with the spacing of 30 cm between rows and 10 cm between plants. It was concluded that spacing 10cmx30cm is optimal for better production of garlic (Mengesha and Tesfaye, 2015). Weeding, cultivation, and ridging were done at the appropriate time to facilitate root, vegetative growth and bulb development. The crop was grown under irrigation with the agronomic managements were applied as per the recommendation made for the crop.

3.4. Soil Analysis Methods

Soil samples were collected randomly from the entire experimental field following a zigzag fashion from 0 to 30 cm depth before planting using an augur. The soil samples that were collected from the entire experimental field was made one kg composite sample and used to determine soil chemical properties. The composite soil sample was air dried, crushed with wooden pestle and mortar to pass through a 2 mm sieve size for the analysis of physical and chemical properties. Total nitrogen, available phosphorus, potassium, organic matter, soil pH, cation exchange capacity (CEC) and soil texture were determined in Mekelle Soil Laboratory. The soil pH was measured in 1:2.5 soil water ratios using an electrode pH meter. Organic carbon content of the soil was determined by Walkley and Black method (Walkley and Black, 1934) while available phosphorus was estimated following the standard procedure of Olsen *et al.,* (1954) and total nitrogen was estimated by the Kjeldahl method (Jackson, 1958).

3.5. Data Collection

Phenology, growth, yield and yield component data of garlic were collected from the three central rows either on the basis of sample plants or plot basis as described below.

Days to 50 % emergence: this was recorded when 50 % of the planted cloves sprouted and emerged out of the soil in each plot.

Days to physiological maturity: physiological maturity was recorded when 75 % of the leaves of the plants in each plot become yellow, dry and/or shown senescence.

Plant height (cm): the average length of the plant in cm was measured from the soil surface to the tip of ten randomly taken plants in each plot at physiological maturity.

Leaf length: the average length of the longest leaf, at physiological maturity was measured in cm from the ten randomly taken plants in the three central rows.

Leaf width: the average width of leaves was recorded from ten randomly taken plants in the three central rows. One leaf from each sample plant was measured at the widest part at the time of physiological maturity.

Leaf number per plant: the total number of healthy leaves was counted from the ten randomly taken plants from middle three central rows at physiological maturity.

Shoot dry weight (g): the total dry weight of above ground biomass was recorded in gram after drying under sun for seven days followed by oven drying at temperature of 70 ^{0}C for 48 hours from ten randomly taken plants. The averages were calculated and above ground dry biological yield weight per plant was recorded.

Bulb neck diameter (cm): The average thickness was measured at the middle narrow point of the bulb neck using graduated caliper in cm. It was measured from ten randomly taken plants from the middle three rows in each plot.

Bulb diameter (cm): bulb diameter was measured from randomly taken five bulbs at the widest point in the middle portion of the bulb using graduated caliper in cm

Bulb length (cm): bulb length was measured form the bulbs which the bulb diameter was measured as indicated above. It was measured at the basal end point from the bottom scar of the bulb to the tip point of the bulb using graduated caliper in cm.

Average bulb weight per plant (g): the average mature bulb weight per plant was recorded after weighting ten bulbs produced in the three central rows and dividing by the number of plants.

Bulb dry weight per plant (g): the average bulb dry matter weight of ten randomly take plants for which the average mature bulb weight was measured in gram after ten days of curing bulbs and drying in oven with a forced hot air circulation at temperature of 70 ^{0}C for 72 hours.

Number of cloves per bulb: the total number of cloves produced from ten randomly taken plants were counted and divided by number of bulbs.

Average clove weight (g): This was recorded as average of the weight of ten randomly taken cloves after curing.

Clove length (cm): the average clove length was recorded as average of five cloves of different sizes which was measured from the base to the tip.

Clove width (cm): the width of the cloves was measured form which the cloves length was measured as indicated above. Clove width was measured at the widest point in the middle portion of the clove using graduated caliper in cm.

Total yield per hectare (t ha^{-1}): total bulb yield of plants grown in three central rows was measured after bulbs were cured or exposed for ten days to sunlight. The yields obtained from plots were converted to hectare base.

Marketable bulb yield per hectare (t ha^{-1}): the bulbs harvested from the three central rows were sorted as healthy bulbs free from defects, disease, and damage and acceptable by the market, weighted and converted to tons per hectare as marketable yield.

Unmarketable yield per hectare (t ha^{-1}): the amount of unhealthy bulbs (defected, diseased, immature, badly stained skins, and damaged, etc.) that did not acceptable by the market were weighted and converted to tons per hectare as unmarketable bulbs.

Marketable and unmarketable bulbs size category: the bulbs that were sorted as marketable and unmarketable bulbs as indicated above were graded into size categories based on diameters of bulbs as very large (Jumbo) (>7.62 cm), large (6.35-7.62 cm), medium (5-6.35 cm) and small (<5cm) (Goldy, 2000).

Cloves size category: cloves of ten bulbs randomly taken bulbs were categorized in to three market sizes and one unmarketable cloves (very small) on the basis of clove weight as very small clove (< 1g), small clove (1-2 g), medium clove (2-3 g), large clove (>3g) in weight (MACB, 2008).

Dry biomass yield per plant (g): it was recorded as the sum total of above ground dry biomass/shoot dry weight and bulb dry weight per plant.

Harvest index (%): was determined as the ratio of bulb dry weight to the total plant dry biomass weight.

3.6. Partial Budget Analysis

Partial budget analysis was employed for economic analysis of fertilizer application and it was carried out for combined bulb yield data. The potential response of crop towards the added fertilizer and price of fertilizers during planting ultimately determine the economic feasibility of fertilizer application (CIMMYT, 1988). To estimate the total costs, the current prices of urea and TSP were collected at the time of planting and market price of garlic bulbs was taken at harvest. The economic analysis was based on the formula developed by CIMMYT (1988) and given as follows:

Gross average bulb yield (kg ha^{-1}) (AvY): was an average yield of each treatment.

Adjusted yield (AjY): was the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers. **AjY = AvY- (AvY-0.1).**

Gross field benefit (GFB): was computed by multiplying field/farm gate price that farmers receive for the crop when they sale it as adjusted yield. **GFB = AjY*field/farm gate price**

Total cost: was the cost of urea and TSP used for the experiment. Their prices were based on 2014 price during planting. The costs of other inputs and production practices such as labor cost for land preparation, planting, weeding, crop protection and harvesting were assumed to remain the same or were insignificant among treatments.

Net benefit (NB): was calculated by subtracting the total costs from gross field benefits for each treatment. **NB = GFB – total cost**

Marginal rate of return (MRR %): was calculated by dividing change in net benefit by change in cost which was the measure of increasing in return by increasing input.

3.7. Data Analysis

The data were subjected to analysis of variance (ANOVA) which was appropriate for the design of the experiment using statistical software of SAS version 9.1.3 (SAS, 2007). Least significant differences at 5% level of probability were computed to delineate the significances between and/or among the treatment means. Correlation analysis was conducted for yield and yield components of garlic.

4. RESULTS AND DISCUSSION

4.1. Pre-planting Soil Sample Analysis

Composite soil sample of the experimental site was analyzed soil texture and chemical properties before planting. The soil was classified under clay soil texture (Table 2). Goronski *et al.* (2010) categorized the texture of Gloucester and surrounding areas based on the size of the soil particles. Sandy soils have very large particles, silt and clay (very fine). Water, air and plant roots can move freely in sandy soil but not in very fine clay.

The total nitrogen content of soil is low 0.104 % (Table 2). Goronski et al. (2010) described that N content of soil between 0.15-0.25 percent is medium and greater than 0.25 % is high. Available phosphorus of soil was categorized within very low (6.5 ppm) which was based on the ranges rated by Egel et al. (2014). Most vegetables will benefit from P fertilization if the soil test is less than 35-40 ppm P using the Bray-Kurtz P_1 extraction method. Also the exchangeable potassium contents of the soil was considered as low content (75.2 ppm) because according to Egel et al., (2014), if the soil test is less than 85 ppm K, it is categorized under low potassium content. There is always some organic matter in soil, but usually not enough for plant's needs. It corrects clay soil by making it looser, so that air, water and roots can penetrate. In all soils, it encourages beneficial microbial activity (Goronski *et al.,* 2010). The experimental soil was characterized by 0.99 % organic carbon and 1.7 % organic matters that were characterized as low. According to Egel et al, (2014), soils having more than 3% organic matter, may not need any side dressing of nitrogen fertilizer. If the soil has less than 3% organic matter, then half the total N can be applied pre-plant and the other half side dressed early in the crop growth cycle.

The soil of experimental site Guahgot FTC had 28 meq/100g cation exchange capacity (CEC) which is moderate according to Egel et al., (2014) who related the soil texture with CEC content, the soil textures like sands, silts, clays and organic soils have 5-15, 8-30, 25-50 and ≥ 50 meq/100 g ranges of CEC, respectively. Cation exchange capacity (CEC) is a measure of the soil's ability to hold exchangeable cations such as hydrogen (H), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), iron (Fe), and aluminum (Al). Cation exchange capacity is measured in terms of milliequivalents (meq) per 100 grams of soil (McCormack, 2012). The experimental site had 0.06 dm/m electron conductivity and pH of 6.8 close to neutral soil property. Garlic prefers a fairly neutral pH, 6.5 to 7.0. Soil that is too acid or too alkaline causes slow growth and late maturity. N is decreasing as soil acidity increasing while highly available as soil alkalinity increasing (McCormack, 2012; Goronski *et al.*, 2010).

The soil sample analysis showed that the experimental site was deficient in some macro and micronutrients. Ethiopian Agricultural Transformation Agency (ATA, 2014) had reported that seven soil nutrients were found to be deficient in the Gantaafeshum district. These are the total nitrogen, available phosphorus, exchangeable potassium, available sulfur and extractable iron, Zinc and boron. The current study results also showed that some of these elements were deficit.

Table 2. Soil Physical and Chemical Properties of the Study Site

Soil parameters		
Soil physical property	**Value**	**Soil Status**
Clay (%)	82	Clay
Silt (%)	7	---
Sand (%)	11	---
Soil Texture	>80 clay	Clay texture
Soil chemical property		
Total N (%)	0.104	Low
Available P (ppm)	6.5	Very low
Available K (ppm)	75.2	low
Organic carbon (%)	0.987	low
Organic matter (%)	1.7	Very low
EC (ds/ml)	0.06	low
CEC meq/100g	28	Medium
pH (1:2.5 H_2O)	6.8	Neutral

N-nitrogen: P-phosphorous: K-potassium: EC-electron conductivity: CEC-cation exchange capacity

4.2. Phenology of the Crop

Days to 50 % plants emergence and days to 75 % physiological maturity were significantly influenced by cultivar and the interaction effect of cultivar by nitrogen fertilizer (Appendix Table-1). The cultivar Guahgot local and Felegdaero without nitrogen fertilizer application were significantly earlier for days to 50 % plants emergence at about 8.98 and 9.78 days, respectively. Cultivar Guahgot local was earlier by 7.44 days than Bishoftu Nech with 41 kg N ha^{-1} application. However, Bishoftu Nech was statistically non-significant with other combinations of treatments in clove emergence (Table-3). It was also observed significant differences among cultivars where the highest number of days to emergency was observed in the improved variety Tsedey (15.55 days after planting) while the Guahgot local cultivar (10.5 days) was earlier in emergence (Appendix Table-3). This may be due to genetic makeup of the cultivars and the interaction with nitrogen fertilizer. Tadesse (2009) stated emergence success was fastest in local cultivar than improved variety of garlic G-99-2. Dickerson and Wall (1993) was also observed significant differences among nine cultivars of garlic in emergence success in New Mexico.

Table 3. Interaction effect of cultivar and nitrogen fertilizer on days to emergency of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Days to 50 % emergence			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	15.16^{a-d}	16.42^{a}	15.21^{a-d}	13.82^{a-g}
Tsedey (G-493)	15.38^{abc}	14.95^{a-e}	15.39^{abc}	15.57^{ab}
Kuriftu	14.22^{a-f}	14.07^{a-g}	12.04^{e-i}	13.42^{b-g}
Felegdaero	9.78^{h-j}	11.58^{f-j}	12.53^{c-h}	12.09^{e-h}
Bora-1	12.19^{e-h}	13.48^{b-g}	12.33^{d-h}	11.51^{f-j}
Bora-2	12.52^{d-h}	12.04^{f-i}	13.91^{a-g}	15.50^{ab}
Guahgot (local)	8.98^{j}	11.54^{f-j}	11.24^{g-j}	9.157^{ij}
Mean	13.071			
S.E. (±)	1.766			
LSD (0.05)	2.903			
CV (%)	13.507			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

However, the non-significant difference was observed to nitrogen fertilizer rates, indicating cultivar genetic makeup influenced than nitrogen fertilizer application in controlling days to emergence. In line with this, nitrogen and phosphorous nutrients did not significantly influence the sprouting and shoot growth stages of garlic (Youssef, 2013; Betewulign and Solomon, 2014).

The interaction effects of cultivars and nitrogen rates was significantly influenced the plant maturity, the earliest maturity was recorded by cultivar Felegdaero at 41 kg N ha^{-1} matured within 145.02 days after planting but this did not statistically differed with all combinations except with Tsedey at 41, 123 kg N ha^{-1}. Bora-1 at application of 41kg N ha^{-1} but non-significant differences was observed among themselves. It was also significantly differed with Bora-2 with combination of 123 kg N ha^{-1} and Guahgot local at 41 kg N ha^{-1} but not statistically significant between themselves. High significant differences were recorded in Guahgot local attained maturity 19 days late from the cultivar Felegdaero without fertilizer application. However, non-significant results were exhibited by Guahgot local without N and fertilized at 82 and 123 kg N ha^{-1}.Abraham et al.(2014) reported that varieties were significantly varied in days to maturity where Tsedey 92 variety took 126 days to mature whereas the local cultivar took seven days more to mature. Kuriftu improved variety and Felegdaero cultivar showed ten days earlier in maturity as compare to Guahgot local which took 158.67 days to be mature. Plant physiological maturity is the stage when a product is capable of further development or ripening i.e. ready for eating or processing (Dhatt and Mahajan, 2007). The results of this experiment indicated that physiological maturity affected by garlic cultivars and their interaction to the applied nitrogen fertilizer either by enhancing or delaying the time required for plant maturity. The interaction effect of garlic varieties and nitrogen fertilizer rates were showed significant differences among the treatment means. Varieties had different morphological and physiological senescence due the genetically and environmental effects but the combined analysis of garlic cultivars with high level of nitrogen could be attributed to delay maturity and extended the physiological activities and photosynthesis (Abraham et al., 2014). Hector et al. (2012) explained that varieties of garlic can be harvested at either 150 (early cycle), 180 (intermediate cycle) or 210 (late cycle) days after planting. They also reported that lines JAS-45 and JAS-46 were early maturing (135 days) lines.

Bulb neck of garlic was taken before ready to harvest when plants were dry yellow and the stem (bulb neck) have not begun to be soften (Kamenetsky, 2007; Rubatzky and Yamaguchi, 2007). It is an indication of optimum maturity of garlic when the bulb neck becomes soft and assimilation of food transportation stops. Optimum harvest at physiological maturity is important to obtained successful planting materials. While if the bulb neck is stiff, the xylem and phloem vessels are also active and can transport water, nutrients and photosynthesis assimilation respectively. Too early harvest produces small bulbs that exhibited rapid weight loss, formed cracked bulbs and wrapped skin (Grieve, 2006; Hickey, 2006).

Table 4. Interaction effect of cultivar and nitrogen fertilizer on days to physiological maturity of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Days to physiological maturity			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	145.333^{g}	145.808^{fg}	$149.260^{c\text{-}g}$	$150.756^{c\text{-}g}$
Tsedey (G-493)	$150.886^{c\text{-}g}$	154.740^{bcd}	$149.887^{c\text{-}g}$	$153.720^{b\text{-}e}$
Kuriftu	$150.845^{c\text{-}g}$	146.571^{efg}	$152.100^{c\text{-}g}$	$152.810^{c\text{-}g}$
Felegdaero	145.441^{g}	145.016^{g}	$147.979^{d\text{-}g}$	$148.582^{d\text{-}g}$
Bora-1	$151.920^{c\text{-}g}$	$154.520^{b\text{-}e}$	$151.808^{c\text{-}g}$	$150.423^{c\text{-}g}$
Bora-2	$148.808^{d\text{-}g}$	$149.989^{c\text{-}g}$	$150.848^{c\text{-}g}$	$153.000^{c\text{-}f}$
Guahgot local	164.330^{a}	157.130^{abc}	163.190^{a}	161.330^{ab}
Mean	151.68			
S.E. (±)	4.934			
LSD (0.05)	8.112			
CV (%)	3.253			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

4.3. Growth of the Garlic Plant

The analysis of variance revealed that plant height, leaf width and bulb neck diameter were significantly influenced by cultivar, nitrogen fertilizer and the interaction of the two. However, leaf length and leaf number per plant were not significantly influenced by the interaction of cultivar and nitrogen fertilizer. Leaf length was significantly influenced by nitrogen fertilizer application while leaf number per plant was influenced by both main factors only (Appendix Table-1).

The longer plant height was recorded by Bishoftu Nech (81.583 cm) at 123 kg ha^{-1} rate of nitrogen fertilizer application, however statistically not significant with Tsedey (G-493) in all rates of N fertilizer except without fertilizer treatment. Moreover the results were not revealed statistically significant among the combine means of Bishoftu Nech and Bora-1 in all rates of nitrogen fertilizer including zero as well as Bora-2 at 82 and 123 kg N ha^{-1}.The longer plant height was higher than Felegdaero and Bora-2 by about 21.99 to 27.31%, both without nitrogen fertilizer application, respectively. Even though the shortest plant height was recorded from Guahgot local (64.07 cm) at N application of 41 kg ha^{-1}, it was not exhibited statistically significant results when the cultivar treated with different nitrogen rates. Besides, non-significant results were obtained with varieties Bishoftu Nech, Felegdaero and Kuriftu at nitrogen application of zero, 41 and 82 kg N ha^{-1} (Table 5).

In general, plant height of all cultivars was increased at the highest level of fertilizer rate. The cultivars had different plant height at different rates of nitrogen fertilizer which might be due to the differences of the cultivars genetic constitute to respond to the applied fertilizer in enhancing meristematic elongation. The growth of garlic was significantly influenced by nitrogen fertilization. Garlic plant height increased from 42.4 to 64.7cm as the nitrogen rates increased from 0 to 200 kg N ha^{-1} (Zaki *et al.*, 2014; Zaman *et al.* 2011). This result agreed with the study of Abraham *et al.* (2014) the difference in plant height was observed significantly differ between the varieties Tsedey 92 and Local throughout the growth period. Under his observation a wide range of variation was measured in plant height among different garlic varieties. Etoh and Simon (2002) also reported wide variation among garlic varieties in plant height. In general, Balady cultivar gave taller plants than Sids-40 one in presence or absence of organic treatments. Similarly, Yudhvir and Ramesh, 2003; Youssef, and Tony, 2014; explained that the data exhibited significant variation in different clones for different characters. Garlic Plant height from the landraces Elgharbia was the longest, while side 40 accessions was the shortest in all seasons (Hazem, 2013). Besides a significantly difference result of plant height were reported by Abou El-Magd, *et al.,* (2012); Panse *et al.,* (2013) based on their perspective garlic cultivar trials. It was also reported that the height of garlic plants was increased due to the highest rate of nitrogen application (125 kg N ha^{-1}) as compared to the shortest plants (83.27cm) observed at zero nitrogen fertilizer (Hossein, *et al.*, 2014).

Table 5. Interaction effect of cultivar and nitrogen fertilizer on plant height of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/2015

	Plant height (cm)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123kg N ha^{-1}
Bishoftu Nech (W-14)	66.333^{h-l}	66.241^{i-l}	66.009^{jkl}	81.583^{a}
Tsedey (G-493)	67.676^{f-l}	77.333^{abc}	74.241^{a-i}	78.500^{ba}
Kuriftu	68.694^{d-l}	67.296^{h-l}	67.787^{e-l}	73.722^{a-j}
Felegdaero	64.352^{lk}	70.667^{b-l}	67.556^{f-l}	72.176^{b-k}
Bora-1	74.319^{a-h}	76.474^{a-d}	75.583^{a-f}	75.833^{a-e}
Bora-2	64.083^{l}	71.583^{b-l}	74.824^{a-g}	76.426^{a-d}
Guahgot local	64.917^{lk}	64.065^{l}	68.667^{d-l}	69.769^{c-l}
Mean	70.953			
S.E. (±)	4.911			
LSD (0.05)	8.077			
CV (%)	6.922			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

Interaction effect of varieties and nitrogen rates showed highly significance differences of leaf width among the treatments. But insignificant results were recorded in nitrogen fertilizer rates (Appendix 1). The widest leaf width was recorded from the cultivar Guahgot local (3.20 cm) when the plant received without nitrogen fertilizer while non-significant results were achieved by this cultivar when it was fertilized by all nitrogen rates. However the smallest leaf width (1.87 cm) was recorded from variety Tsedey (G-493) with no nitrogen fertilizer and at application of 82 kg N ha^{-1} without significance difference between them. Similarly varieties Bishoftu Nech at application of 82 kg N ha^{-1}, Felegdaero, Kuriftu, Bora-1 and Bora-2 were also showed non-significant results in all rates of nitrogen fertilizer as compare to Tsedey recorded the smallest leaf width.

In general, Tsedey was narrower by 44.38% than the widest leaf width at zero nitrogen fertilizer. The Guahgot local cultivar was superior in plant leaf width over other cultivars at all rates of nitrogen fertilizer application. These results showed that leaf width was more related to the function of genetic makeup in the cultivars than the application of nitrogen fertilizer. Yudhvir and Ramesh (2003) also observed highly significant differences of leaf width in their study among cultivar.

Table 6. Interaction effect of cultivar and nitrogen fertilizer on leaf width of seven garlic cultivars (FTC) in Gantaafeshum district during 2014/15

	Leaf width (cm)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	2.09^{e-h}	2.43^{cde}	2.04^{e-h}	2.31^{d-g}
Tsedey (G-493)	1.87^{h}	2.62^{bcd}	2.29^{d-h}	2.35^{def}
Kuriftu	1.93^{fgh}	2.09^{e-h}	2.01^{e-h}	2.10^{e-h}
Felegdaero	2.00^{e-h}	2.11^{e-h}	2.07^{e-h}	2.22^{d-h}
Bora-1	1.91^{gh}	2.05^{e-h}	2.18^{e-h}	2.18^{d-h}
Bora-2	2.03^{e-h}	2.28^{d-h}	2.29^{d-h}	2.28^{d-h}
Guahgot local	3.20^{a}	2.84^{abc}	2.99^{ab}	2.95^{ab}
Mean	2.275			
S.E. (±)	0.264			
LSD (0.05)	0.435			
CV (%)	11.614			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Highly significant differences were observed in bulb neck diameter among the combined treatments of variety with nitrogen rates. Guahgot local cultivar had significantly thicker bulb neck (1.85 cm) without nitrogen and (1.66) at nitrogen rate of 82 kg ha^{-1} but no statistically significance difference between them. This local cultivar had been shown more of vegetative growth than bulb development. The narrower bulb neck diameter was recorded from cultivar Bora-1 (2.01cm) at application of 82 kg N ha^{-1} but non-significance difference with the same cultivar at all nitrogen fertilizer rates besides Bishoftu Nech at application of zero and 82 kg N ha^{-1}, variety Tsedey without nitrogen fertilizer, Felegdaero in 41 kg N ha^{-1} and Bora-1 and 2 at all rates of nitrogen fertilizer. Medium neck diameter was recorded from the rest treatment combination. Bulb neck diameter was found minimum in JAS-3 (0.71 cm) and it was exhibited maximum in line JAS-25 (1.76 cm) (Panse, et al., 2013). This differences could be highly influenced by the genetic makeup than nitrogen fertilizer application, this is in line with the studies of Hazem, (2013); Farooqui et al. (2009), who showed significance results of varieties than nitrogen fertilizer due to genetics influence.

Table 7. Interaction effect of cultivar and nitrogen fertilizer on bulb neck diameter of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Bulb neck diameter (cm)			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	1.10^{ghi}	1.44^{bcd}	1.15^{e-i}	1.37^{c-f}
Tsedey (G-493)	1.22^{d-i}	1.39^{ecd}	1.34^{c-g}	1.46^{bcd}
Kuriftu	1.09^{ghi}	1.14^{e-i}	1.24^{d-i}	1.12^{f-i}
Felegdaero	1.15^{e-i}	1.43^{bcd}	1.02^{i}	1.08^{ghi}
Bora-1	1.13^{f-i}	1.10^{ghi}	1.02^{i}	1.26^{d-i}
Bora-2	1.16^{e-i}	1.05^{hi}	1.10^{ghi}	1.29^{d-h}
Guahgot local	1.85^{a}	1.31^{d-g}	1.66^{ab}	1.59^{bc}
Mean	1.259			
S.E. (±)	0.158			
LSD (0.05)	0.259			
CV (%)	12.530			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Unlike the other growth parameters, numbers of leaves per plant and leaf length were not significantly influenced by the interaction of cultivar and nitrogen fertilizer. Cultivars showed no significant difference for number of leaves per plant and leaf length. Similarly the absence of significant differences among garlic cultivars for number of leaves per plant was reported by Hazem, (2013) and Tibebu et al., (2014).

Both average numbers of leaves per plant and leaf length were significantly influenced by nitrogen fertilizer. Sufficient quantity of nitrogen is very important for proper growth and development of the plant because it is critical component of chlorophyll. In nitrogen nutrient deficient soils, chlorophyll can’t prepare well which reduce the green color, size and shape of the leaves and necrosis is results (Nori *et al.,* 2012). This is due to the integral function of nitrogen in the leaves which plays greater role in synthesizing of chlorophyll for photosynthesis which improves the cell division and growth. Leaf is the main part of the shoot and primary photosynthesis organ which plays in food preparation. Leaves have different shapes and sizes help to adapted adverse environmental conditions (Wiedenhoeft, 2006). Similarly, Betewulign and Solomon (2014) reported leaf length and leaf number per plant were significantly influenced by application of nitrogen fertilizer rates. The maximum leaf number per plant (10.83) obtained by the application of 125 kg N ha^{-1} while the lowest leaf number per plant (7.83) was at zero treatment of nitrogen fertilizer (Hossein *et al.,* 2014).

The longer leaf length (54.41cm) was attained by the application of 123 kg N ha^{-1} whereas the lowest leaf length (49.05cm) was measured in plot that did not receive nitrogen fertilizer, which was statistically non-significant compared with nitrogen rates of 41 and 82 kg ha^{-1}.

Table 8. Effect of nitrogen fertilizer on leaf number per plant and leaf length of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

kg N ha^{-1}	Leaf length (cm)	Leaf number per plant
0	49.058[b]	12.26[b]
41	51.257[b]	12.55[b]
82	50.189[b]	12.63[b]
123	54.414[a]	13.52[a]
Mean	51.23	12.74
S.E. (±)	4.49	1.180
LSD (0.05)	2.858	0.755
CV (%)	9.10	9.600

Means represented with same letter(s) in columns in each trait and treatment are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

4.4. Yield and Yield Components

4.4.1. Bulb Characters

Average fresh and dry bulb weights, bulb diameter and bulb length were significantly influenced by the interaction effect of cultivar and nitrogen fertilizer application (Appendix Table 1). The highest fresh bulb weight was recorded from Tsedey (G-493), Bora-1, and Felegdaero fertilized at the highest rate of N (123 kg N ha^{-1}) with respective bulb weight of 43.39 g, 43.32 g and 43.25 g. These treatment combinations were not statistically significance difference with Bishoftu Nech, Kuriftu, Felegdaero and Bora-2 with cultivars fertilized from 41-123 kg N ha^{-1}. Moreover non-significant results were recorded from cultivar Bora-1 at all nitrogen fertilizer rates. However, the lowest fresh bulb weight was produced by the cultivar Guahgot local at no nitrogen fertilizer which was 54.39% lower than from the highest average fresh bulb weight while statistically non-significant cultivar Guahgot local along all nitrogen rates. In general across all cultivars the average fresh bulb weights had increasing trends at application 123 kg N ha^{-1} but low at 0 kg N ha^{-1} (Table 9).

On the other hand, significantly the highest bulb dry weight (14.81 g) was recorded from Felegdaero cultivar at application of 123 kg N ha^{-1} but there were not statistically significance when cultivar Felegdaero combined with 41, 82 kg N ha^{-1} and variety Tsedey fertilized at 123kg N ha^{-1}. Even though cultivar Guahgot local recorded the lowest bulb dry weight of 3.31g at zero nitrogen fertilizer application, did not statistically significant with Kuriftu at zero kg N ha^{-1}. The other cultivar and N combinations had shown medium dry bulb weight significantly (Table 10). The fresh and dry bulb weights of the cultivars were the highest at highest nitrogen fertilizer rates. However, the increase of bulb weight was not linear with increase in nitrogen fertilizer rates responded in all cultivars. This indicated that cultivars differentially to the different rates of nitrogen fertilizer because of a greater morphologic variability in agronomic traits among the accessions (Matus *et al.*, 1998; Volk *et al*., 2004)**.** The significant differences among garlic cultivars due to the application of fertilizers was reported by many authors (Yudhvir and Ramesh, 2003; Hector *et al.,* 2012 and Abedi *et al.*, 2013). Similarly, the existence of significant variation among garlic cultivars for fresh and dry bulb weight was reported by Youssef, (2013) and Tibebu, et al. (2014). Hore et al. (2014) reported the fresh bulb weight was increased from 19.23 to 25.15g with the increased level nitrogen fertilizer from 50 to 200 kg ha^{-1}. Beside Farooqui et al. (2009) also observed the application of 200 kg N ha^{-1} significantly increased fresh weight of bulb (48.67g) in comparison to 50 kg N ha^{-1} and 100 kg N ha^{-1}. Nori et al. (2012) also reported that the highest dry bulb weight was obtained from the highest rates of nitrogen fertilizer application.

Table 9. Interaction effect of cultivar and nitrogen fertilizer on the average bulb weight per plant of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Average fresh bulb weight per plant (g)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	31.98^{c-g}	36.32^{a-e}	37.02^{a-e}	40.93^{abc}
Tsedey (G-493)	29.09^{e-h}	37.17^{a-e}	35.81^{a-f}	43.39^{a}
Kuriftu	30.65^{d-g}	32.45^{c-g}	30.89^{d-g}	34.73^{a-f}
Felegdaero	33.75^{b-f}	36.77^{a-e}	37.98^{a-e}	43.25^{a}
Bora-1	35.11^{a-f}	40.53^{abc}	41.97^{ab}	43.32^{a}
Bora-2	27.01^{f-i}	36.73^{a-e}	34.50^{a-f}	38.43^{a-d}
Guahgot local	19.79^{i}	20.67^{hi}	21.51^{hi}	23.38^{hgi}
Mean	34.112			
S.E. (±)	5.5156			
LSD (0.05)	9.0705			
CV (%)	16.169			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

Table 10. Interaction effect of cultivar and nitrogen fertilizer on average dry weight of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/2015

	Average dry bulb weight per plant (g)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	6.68^{hij}	8.50^{fgh}	9.79^{efg}	10.14^{def}
Tsedey (G-493)	7.02^{hij}	$7.45^{g\text{-}j}$	$7.85^{f\text{-}i}$	13.57^{ab}
Felegdaero	10.03^{ef}	12.67^{abc}	13.57^{ab}	14.81^{a}
Kuriftu	5.15^{jk}	6.32^{hij}	$7.46^{g\text{-}j}$	$11.27^{b\text{-}e}$
Bora-1	11.07^{cde}	$12.10^{b\text{-}e}$	12.43^{bcd}	$11.38^{b\text{-}e}$
Bora-2	5.97^{ij}	6.39^{hij}	8.38^{fgh}	11.16^{cde}
Guahgot local	3.31^{k}	6.93^{hij}	6.46^{hij}	5.69^{ij}
Mean		9.056		
S.E. (±)		1.439		
LSD (0.05)		2.367		
CV (%)		15.89		

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

The bulb diameter was significantly influenced by the interaction effects of variety and nitrogen fertilizer (Appendix table-1). The height bulb diameter (5.92 cm) was recorded from cultivar Felegdaero but it was not statistically significance with all rates of nitrogen interaction. Besides, cultivars Bora-1 with all rates of nitrogen fertilizer, Bishoftu Nech at 82 and 123 kg N ha^{-1} and Tsedey also at 82 and 123 kg N ha^{-1} were showed insignificant results with cultivar Felegdaero. However, the narrower bulb diameter was recorded from cultivar Guahgot local which was lowered from Felegdaero with the range of 62.36 to 89.83%. Though there were not significant differences among most combinations of variety and N rates, Bora-1 was recorded a bulb diameter of 5.77 cm and 5.79 cm and it had under the higher bulb diameter categories at an application of 82 and 123 kg N ha^{-1} fertilizer application (Table 11).

The significant effect of the interaction of cultivar and nitrogen fertilizer on bulb diameter was reported by Carolin et al. (2007); Hector et al. (2012) and Youssef, (2013) which is in agreement with the current study results. However, Tibebu *et al.* (2014) reported that all interaction effects among variety, N and P on mean bulb diameter were non-significant. Yudhvir and Ramesh (2003) reported bulb diameter of 5.53 cm as maximum while Singh *et* *al.* (2012) reported 4.84 cm as the highest bulb diameter. It was reported by many researchers in different countries that the bulb diameter of garlic ecotypes varied from 4.32 to 6.62 cm (Etoh and Simon, 2002; Abedi *et al.,* 2013). These results of the current study were showed similar to the work of Zaman et al. (2011) who reported the maximum bulb diameter was recorded from plants grown with 150 kg N ha^{-1}, but the minimum value was recorded in the control. Farooqui et al. (2009) also observed similar results, at application of 200 kg N ha^{-1} significantly increased bulb diameter (5.03cm) as compare to 50 kg N ha^{-1} and 100 kg N ha^{-1}.

Table 11. Interaction effect of cultivars and nitrogen fertilizer on bulb diameter of seven garlic cultivars at Guahgot (FTC) in the Gantaafeshum district during 2014/15

	Bulb diameter (cm)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	5.17^{b-f}	5.57^{bac}	5.13^{b-f}	5.42^{a-d}
Tsedey (G-493)	4.64^{f}	5.20^{a-f}	5.18^{b-f}	5.81^{ba}
Kuriftu	4.98^{c-f}	5.01^{c-f}	4.69^{ef}	5.17^{b-f}
Felegdaero	5.23^{a-f}	5.38^{a-e}	5.25^{a-f}	5.92^{a}
Bora-1	5.47^{a-d}	5.64^{bac}	5.77^{ba}	5.79^{ba}
Bora-2	4.77^{def}	5.15^{b-f}	5.11^{b-f}	5.44^{a-d}
Guahgot local	3.12^{g}	3.32^{g}	3.35^{g}	3.48^{g}
Mean	5.00			
S.E. (±)	0.44			
LSD (0.05)	0.72			
CV (%)	8.76			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

Only considering the cultivar and nitrogen fertilizer separately, the cultivar Felegdaero, Bora 1, Bishoftu Nech and Tsedey were exhibited the maximum bulb diameter of 5.46, 5.42, 5.38 and 5.27 cm respectively without statistically significance difference among themselves while the lowest bulb diameter (3.79 cm) was recorded from cultivar Guahgot local. In addition the maximum bulb diameter (5.33) was recorded from application of the highest nitrogen rate (123 kg Nha^{-1}) whereas the lowest from control (Appendix table 4).

The combine effect of cultivar and nitrogen, the highest bulb length was recorded 6.31cm from Bishoftu Nech (W-14) variety but not statistically non-significant with cultivars Tsedey

(5.96 cm) at 123 kg N ha^{-1}, Bora-1 (5.76 cm and 5.83 cm) at 82 and 123 kg N ha^{-1} as well as Guahgot local (5.85 cm) at 82 kg N ha^{-1} respectively. However, cultivar Felegdaero was recorded the smallest bulb length of 4.82 cm at no nitrogen fertilizer application. Moreover it was not statistically significant with other treatment combinations except Tsedey at 41 kg N ha^{-1}, Kuriftu at 123 kg N ha^{-1} and Bora-2 at 82 and 123 kg N ha^{-1}. In line with this study, the presences of significant differences in bulb length among garlic cultivars were reported by Panse, et al. (2013). The significant effect of nitrogen fertilizer rates on bulb length was also reported by Zaman et al. (2011) that highest length of bulb (3.12 cm) was recorded in 150 kg N ha^{-1} followed by 200 kg N ha^{-1} (3.05 cm) and 250 kg N ha^{-1} (3.03 cm), the last two treatments being statistically identical. The lowest bulb length (2.28 cm) was found in the control plots that received no fertilizer.

Table 12. Interaction effect of cultivars and nitrogen fertilizer on bulb length of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Bulb length (cm)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	5.12 $^{e-h}$	5.41 $^{b-h}$	6.32 ^{a}	5.63 $^{b-f}$
Tsedey (G-493)	5.23 $^{c-h}$	5.49 $^{b-g}$	5.45 $^{b-h}$	5.96 ^{ab}
Kuriftu	5.02 ^{fgh}	5.23 $^{c-h}$	5.20 $^{d-h}$	5.47 $^{b-g}$
Felegdaero	4.82 ^{h}	4.90 ^{gh}	5.10 ^{fgh}	5.21 $^{c-h}$
Bora-1	5.29 $^{c-h}$	5.45 $^{b-h}$	5.76 $^{a-e}$	5.83 $^{a-d}$
Bora-2	4.98 ^{fgh}	5.29 $^{c-h}$	5.56 $^{b-f}$	5.56 $^{b-f}$
Guahgot local	5.61 $^{b-f}$	5.38 $^{b-h}$	5.85 ^{abc}	5.08 ^{fgh}
Mean	5.401			
S.E. (±)	0.395			
LSD (0.05)	0.649			
CV (%)	7.110			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

4.4.2. Clove Characters

The applied of nitrogen fertilizer and cultivar interacted to influence significantly the number of cloves per bulb, average clove weight, clove length and width. These characters were also significantly affected by cultivar; moreover, nitrogen fertilizer application alone had significant influence on number of clove per bulb and cloves diameter (Appendix Table 1). Tsedey and Bishoftu Nech exhibited the highest number of cloves per bulb 26.96 and 26.43, respectively at 123 kg N ha^{-1} fertilizer application. But these had not statistically significance difference with Bishoftu Nech at 41 and 82 kg N ha^{-1} as well as Tsedey at 41 kg N ha^{-1}. While cultivars Bora-1 recorded the lowest number of cloves 13.79 at 123 kg N ha^{-1} fertilizer application but not statistically significant with cultivar Felegdaero at all rates except 82 kg N ha^{-1}, Bora-2 and Guahgot local at zero and 41 kg N ha^{-1}. Bishoftu Nech (W-14) and Tsedey (G-493) showed superiority over Bora-1 and Bora-2 by greater than 45.3% at the 123 kg N ha^{-1} fertilizer application (Table 13).

Most interaction of cultivars responded to increased nitrogen fertilizer rates linearly in producing number of cloves per bulb. However, some interactions of the cultivars with N fertilizer rates did not show defined trend in producing number of cloves per bulb at the increased rates of fertilizer application due their genetic potential of the varieties. This showed that increased application of nitrogen fertilizer also increased the number of cloves per bulb. Yudhvir and Ramesh, (2003) also observed maximum number of cloves per bulb at highest rate of potassium fertilizer application in local cultivar which produced an average 30.77 cloves per bulb. Similar to the current study, significant variation among garlic cultivars for number of cloves per bulb was reported by other authors (Hector *et al.*, 2012; Hossein *et al.*, 2014). According to Zaman et al. (2011) the highest number of cloves per bulb (20.35) was obtained from 150 kg N ha^{-1} and the lowest (13.62) was found in the control treatment. Hossein et al. (2014) reported very low number cloves per bulb that was (13.67) as maximum achieved by the application of 125 Kg N ha^{-1} while the lowest clove number per bulb (9.83) was obtained at zero nitrogen fertilizer application.

Table 13. Interaction effect of cultivar and nitrogen fertilizer on number of cloves per bulb of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum District during 2014/15

Cultivar	Number of cloves per bulb			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	23.03 ^{cd}	24.52 ^{abc}	24.35 ^{abc}	26.43 ^{ab}
Tsedey (G-493)	22.72 ^{cde}	24.78 ^{abc}	22.43 $^{c-f}$	26.96 ^{a}
Kuriftu	19.83 $^{e-h}$	20.87 $^{d-g}$	19.49 $^{f-i}$	23.44 ^{bcd}
Felegdaero	15.21 ^{klm}	16.06 $^{j-m}$	18.69 $^{g-j}$	16.51 $^{i-m}$
Bora-1	14.06 ^{m}	15.64 $^{j-m}$	17.24 $^{h-l}$	13.79 ^{m}
Bora-2	16.18 $^{j-m}$	14.64 ^{lm}	17.38 $^{h-l}$	17.79 $^{g-k}$
Guahgot local	16.16 $^{j-m}$	16.33 $^{j-m}$	17.31 $^{h-l}$	17.75 $^{g-l}$
Mean	19.27			
S.E. (±)	1.898			
LSD (0.05)	3.121			
CV (%)	9.847			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

The cultivar Bora-1 in combination with 82 kg N ha^{-1} recorded the maximum average clove weight (4.48g) but statistically non-significant with different rates of nitrogen in the same cultivar. Moreover it was not significance with Bora-2 and Felegdaero cultivars at 123 kg N ha-1 fertilizer application. While the smallest average clove weight (2.69g) was attained by cultivar Tsedey (G-493) with combination of no nitrogen fertilizer application but insignificant with variety Tsedey and Guahgot local at all rates of nitrogen fertilizer. The Bora-1 cultivar was produced heavier cloves than the variety Tsedey by 33.93 up to 39.96 % weight difference (Table14).The number of cloves per bulb may not express the size of bulb because sometimes, it is inversely related with size of the cloves (McCormack, 2012; Farooqui *et al.,* 2009). This study was shown similar range with the study of Hazam, (2013) obtained the average clove weight in the range of 1.79 to 4.78 g; Yudhvir and Ramesh, (2003) obtained the maximum average clove weight of 3.63g from one cultivar but the other had small and varied weight of cloves.

Table 14. Interaction effect of cultivar and nitrogen fertilizer on average clove weight of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Average clove weight (g)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	2.81^{ij}	2.86^{ij}	3.28^{e-j}	3.26^{e-j}
Tsedey (G-493)	2.70^{j}	3.33^{d-i}	3.27^{e-j}	3.34^{d-i}
Kuriftu	3.28^{e-j}	2.93^{hij}	3.35^{d-i}	3.19^{f-j}
Felegdaero	3.65^{b-g}	3.78^{b-f}	3.87^{b-e}	$4.12^{a\ b}$
Bora-1	3.90^{a-d}	3.91^{a-d}	4.48^{a}	3.99^{abc}
Bora-2	3.13^{g-j}	3.37^{d-i}	3.50^{c-h}	$4.22^{a\ b}$
Guahgot local	2.72^{j}	2.96^{hij}	3.10^{g-j}	2.82^{ij}
Mean		3.398		
S.E. (±)		0.371		
LSD (0.05)		0.610		
CV (%)		10.92		

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Clove diameter and length determines the size of bulbs to be either large or small size as a result it contributes to the total bulb yields. According to Masoumi *et al*., (2006) cultivars had shown different clove diameters and lengths which contributed in the major area and dimensions of the clove. The interaction between cultivar and nitrogen was significant in determining clove diameter. The widest clove diameter (2.39 cm) was obtained from cultivar Bora-1at 82 kg ha^{-1} nitrogen fertilizer application but statistically insignificant showed in same cultivar and cultivar Felegdaero in all rates nitrogen fertilizer. Besides, Bora-2 was showed insignificant results with cultivar Bora-1 at application of 41-123 kg N ha^{-1}.

However, the lowest clove diameters were recorded in Tsedey (G-493) and Guahgot local cultivars which exhibited 1.53 cm and 1.55 cm diameters respectively. The cultivar Tsedey and Guahgot local were not statistically significance difference with all rest interaction treatments of variety and nitrogen fertilizer, except Bishoftu without N fertilizer, Tsedey at 82 kg N ha^{-1} and Kuriftu at 82 kg N ha^{-1}. Therefore, cultivar Bora-1 had 35.42 % superior clove diameter over Guahgot local (Table 15).

Table 15. Interaction effect of cultivar and nitrogen fertilizer on clove diameter of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Clove diameter (cm)			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech	1.66^{f-h}	1.65^{ghi}	1.80^{d-i}	1.81^{d-i}
Tsedey (G-493)	1.53^{i}	1.81^{d-i}	1.93^{b-h}	1.85^{d-i}
Kuriftu	1.77^{d-i}	1.88^{c-i}	1.92^{c-h}	1.89^{c-i}
Felegdaero	2.24^{abc}	2.15^{a-d}	2.26^{abc}	2.26^{abc}
Bora-1	2.30^{ab}	2.38^{ab}	2.39^{a}	2.40^{a}
Bora-2	1.97^{b-g}	2.24^{abc}	2.08^{a-e}	2.03^{a-f}
Guahgot local	1.55^{hi}	1.88^{c-i}	1.53^{i}	1.63^{ghi}
Mean	1.956			
S.E. (±)	0.228			
LSD (0.05)	0.375			
CV (%)	11.664			

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

The interactions of varieties and nitrogen effect showed significance differences among the treatment means on the clove length. The highest clove length was recorded from both Bora-1 (4.34 cm) and Bora-2 (4.29cm) at application of 82 and 123 kg N ha^{-1} respectively. But there were not a significance differences among the cultivars all treated with 123 kg N ha^{-1} except Guahgot local. Similarly statistically insignificant longer cloves were recorded in varieties Tsedey, Kuriftu, Bora-1 and 2 at application of 41 kg N ha^{-1} except in Bishoftu and Felegdaero cultivars. While the shortest clove length was recorded from Guahgot local (2.48 cm) without nitrogen fertilizer application, similarly this local cultivar did not showed statistically significant differences among the nitrogen fertilizer rates. The average clove length of cultivar Bora-1 was higher than Guahgot local by over 46 % without nitrogen fertilizer.

Table 16. Interaction effect of cultivar and nitrogen fertilizer on clove length of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Clove length (cm)			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	3.358^{gh}	3.425^{fg}	3.458^{efg}	3.950^{a-g}
Tsedey (G-493)	3.642^{c-g}	3.850^{a-g}	3.692^{b-g}	3.850^{a-g}
Kuriftu	3.708^{b-g}	3.775^{a-g}	3.833^{a-g}	3.775^{a-g}
Felegdaero	3.517^{d-g}	3.625^{c-g}	3.675^{b-g}	3.717^{a-g}
Bora-1	4.050^{a-f}	4.083^{a-e}	4.342^{a}	4.233^{abc}
Bora-2	3.650^{c-g}	4.133^{a-d}	4.292^{ab}	4.300^{ab}
Guahgot local	2.483^{i}	2.792^{hi}	2.500^{i}	2.492^{i}
Mean	3.650			
S.E. (±)	0.384			
LSD (0.05)	0.632			
CV (%)	10.522			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

4.4.3. Shoot Dry Weight, Dry Biological Yield and Harvest Index

The interaction of cultivar and nitrogen fertilizer had significant influence on shoot dry weight and total biological yield. However, harvest index was not significantly influenced by the interaction of the two but it was influenced only by cultivar (appendix Table 1).

The highest shoot dry weight per plant (6.57 g) was recorded with cultivar Guahgot local at 123 kg ha^{-1} nitrogen fertilizer application, but it gave non-significant result with variety Tsedey (G-493) at application 82 and 123 kg N ha^{-1}. However, the lowest shoot dry weight (2.49 g) was recorded from variety Kuriftu without nitrogen fertilizer but except Guahgot local all the six cultivars were showed statistically non-significant results with Kuriftu variety without nitrogen fertilizer application. Similarly, cultivar Felegdaero was showed insignificant result across all rates of nitrogen fertilizer. This cultivar which had the highest shoot dry weight gave over 44.60 to 62.10 % weight increases as compare to variety Kuriftu at no nitrogen fertilizer application (Table 17). These results might be expected based on the genetic background of each cultivar and the variable climatic condition requirements of genotypes; it could be attributed in plant height and leaf number per plant as increased the shoot dry weight of the plant (Zaki *et al*, 2014; Abreham *et al.* 2014)

Abou El-Magd et al. (2012) measured the highest and lowest shoot dry weight of 5.95 g and 2.45g from Egaseed and Balady varieties, respectively. Hossein et al. (2014) reported relatively higher shoot dry weight of 6.38 g from Hamedan while the lowest shoot dry weight (4.03 g) was measured from the cultivar Violet. Hossein et al. (2014) also reported that the maximum shoot dry weights (7.01g) was achieved on the application of 125 kg N ha^{-1} which was close to the amount used in study while the lowest shoot dry weights (3.41g) was achieved at zero treatment of nitrogen fertilizer.

This was in agreement with the findings of Kahane et al. (1997) and Takagi, (1990) the influence of environmental factors, such as temperature, day length and carbohydrates has been often stated development and growth in garlic plant. Kamenetsky et al. (2004) also indicated that garlic morphology and plant development indicating that the environmental regulatory effect is obligatory and yet quantitative in certain varieties.

Table 17. Interaction effect of cultivar and n fertilizer on shoot dry weight of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivars	Shoot dry weight (g)			
	0 N-rate	41 N ha^{-1}	82 N ha^{-1}	123 N ha^{-1}
Bishoftu Nech (W-14)	3.236^{ijk}	4.595^{c-g}	4.933^{b-d}	4.512^{c-h}
Tsedey (G-493)	3.539^{g-k}	4.044^{d-i}	5.419^{ab}	5.341^{abc}
Kuriftu	2.488^{k}	3.269^{h-j}	3.770^{e-j}	3.645^{f-k}
Felegdaero	2.712^{jk}	2.710^{jk}	3.142^{ijk}	3.376^{g-k}
Bora-1	3.675^{f-k}	3.783^{e-j}	3.792^{e-j}	3.832^{d-j}
Bora-2	3.190^{ijk}	3.469^{g-k}	4.168^{c-i}	4.202^{c-i}
Guahgot local	4.544^{b-g}	4.794^{b-f}	5.067^{bcd}	6.568^{a}
Mean	3.993			
S.E. (±)	0.756			
LSD (0.05)	1.244			
CV (%)	18.94			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

The interaction effects of variety and nitrogen were significantly affecting the dry biological yield per plant. It is sum total of underground and aboveground dry matter yield. As increased, the dry biological yield increasing food assimilation of a plant even if the genetic performance of increasing rate of the cultivars differed due to their potential. Below, 2001 stated increases in crop productivity due to variety and fertilizer N additions may be realized as dry matter yield, protein yield, or an improvement in quality factors. Different cultivars grown at the same location can exhibit different response patterns to N fertilization. The results obtained in this study support the findings of Abou El-Magd, *et al.,* 2012 where a significant increment in canopy dry matter yield of garlic was reported as N application increased. Similarly Hossein *et al.,* 2014 reported a significant increase in dry matter yield of garlic.

The highest total dry biomass yields per plant were produced from Variety Tsedey (G-493) (18.91 g), Felegdaero (18.19 g) and Bora-1(16.26 g) at an application of 123 kg N ha^{-1} without significance differences among them. While the lowest dry biomass yield per plant were recorded from Guahgot local, Kuriftu, Bora-2 and Bishoftu Nech which exhibited 8.37 g, 8.95 g, 9.92 g, and 9.44g at zero nitrogen fertilizer rates, respectively. Likewise, these cultivars were not produced statistically significance difference with variety Kuriftu at 41 and 82 kg N ha^{-1} as well as Bora-2 at 41 kg N ha^{-1} fertilizer application (Table 18). In general, the highest dry biomass yield per plant was differed from the lowest by 50.08 to 55.74 % dry total yield. ElHifny, 2010 reported significant differences among cultivars and NPK fertilizer rates in bulb dry weight and percent of dry matter of Chinese garlic

Table 18. Interaction effect of cultivar and nitrogen fertilizer on dry biomass yield of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Dry biomass yield per plant (g)			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	9.919^{j-m}	13.433^{d-h}	14.385^{c-g}	14.652^{c-g}
Tsedey (G-493)	11.385^{h-l}	11.494^{h-l}	12.443^{f-j}	18.914^{a}
Kuriftu	8.916^{lm}	9.589^{klm}	9.952^{i-m}	14.912^{c-g}
Felegdaero	12.739^{e-h}	15.383^{cde}	16.715^{abc}	18.190^{ab}
Bora-1	14.862^{c-g}	15.058^{c-f}	15.880^{bcd}	16.262^{abc}
Bora-2	9.442^{lm}	9.583^{klm}	12.548^{f-j}	15.359^{cde}
Guahgot local	8.373^{m}	11.251^{h-l}	11.474^{h-l}	12.262^{g-k}
Mean	13.05			
S.E. (±)	1.698			
LSD (0.05)	2.792			
CV (%)	13.01			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

4.4.4. Total Bulb Yield (t ha^{-1})

The interaction effects of cultivar and nitrogen fertilizer showed a significance difference among the treatment means in total bulb yield. Total bulb yield increased with increase of N fertilizer, except in cultivar Bora-1, which decreased at 123 kg N ha^{-1}. Even though, the cultivar Bora-1 produced significantly highest total bulb yield (12.61 t ha^{-1}) at application of 82 kg N ha^{-1}, it was not statistically significance difference with application of 41 and 123 kg N ha^{-1} as well as with variety Tsedey at application 123 kg N ha^{-1}. While the lowest bulb yield were recorded from cultivar Guahgot local (5.31 t ha^{-1}) without nitrogen fertilizer application and at 41 kg N ha^{-1} with no significance differences between them. The other combinations were showed yield performance in between the highest and the lowest with significantly differed among themselves.

The yield difference between Bora-1 and Guahgot was between 104.26 to 137.27% at the indicated rates of fertilizer which produced highest and lowest yield. The cultivar Bora-1 showed superiority over the released varieties Bishoftu Nech (W-14), Tsedey (G-493), and Kuriftu by about 13.87, 15.97 and 28.74% without fertilizer application. This cultivar showed maximum yield advantages of 28.07, 26.88 and 36.40 % over Bishoftu Nech (W-14), Tsedey (G-493) and Kuriftu at 82 kg N ha^{-1} fertilizer application, respectively. However, the yield advantage of this cultivar over the three released varieties was reduced at 123 kg N ha^{-1} fertilizer application which ranged between 4.63 to 22.22%.

The yield of all cultivars increased as the rates of nitrogen fertilizer increased except the cultivar Bora-1 which had 2.67 % lower bulb yield at 123 kg N ha^{-1} as compared to its yield at 82 kg N ha^{-1} rate. The maximum yield increase of 28.85, 28.17 and 26.34 % were obtained from Kuriftu, Tsedey (G-493) and Guahgot local respectively, at 123 kg N ha^{-1} as compared to zero fertilizer application. The high yielding cultivar Bora-1 showed yield increment at 41 kg N ha^{-1} as compared to yield obtained without fertilizer application. The yield increase was 19.16 % but further increase to 82 kg N ha^{-1} resulted in only increase 5.59 % over the yield obtained at 41 kg N ha^{-1} (Table 19).

The present study revealed that cultivars produced maximum yield at different nitrogen fertilizer rates. Similar result was reported by Abreham *et al.,* 2014, that garlic cultivars produced maximum total bulb yield at different rates of nitrogen fertilizer application. He reported the bulb yield of the local (farmers') variety increased from 0.67 to 2.31 t ha^{-1} as the level of N application increased from zero to 150 kg ha^{-1} while it was increased 0.67 to 1.85 t ha^{-1} under no N applied. Tsedey 92 variety and local cultivar produced maximum total bulb yield at 100 kg N ha^{-1}.

It was reported that the significant differences among garlic cultivars in total bulb yield in the range between 10.24 to 7.76 t ha^{-1} (Hossein *et al*., 2014; Youssef, 2013). Relatively low yield was reported by Kilgori et al. (2007) in the range between 5.84 to 8.02 t ha^{-1}. Hossein et al. (2014) reported the maximum bulb yield of 9.65 t ha^{-1} at 100 kg N ha^{-1} and the lower yield (8.13 t ha^{-1}) at zero rate of nitrogen. They also indicated non-significant bulb yield difference between 50 and125 kg N ha^{-1} fertilizer applications suggesting that 50 kg N ha^{-1} was sufficient to obtain good bulb yield.

Hore et al. (2014) also observed low yield per hectare increase of 5.7 to 7.6 t ha^{-1} with increasing level of nitrogen from 50 to 200 kg ha^{-1}. In Chile, Ruiz (1986) reported that increasing rate of applied nitrogen from 0 to 150 kg ha^{-1} increased bulb yield from 4.6 to 10.6 t ha^{-1}. Farooqui et al. (2009) observed that the application of 200 kg N ha^{-1} significantly increased bulb yield (16.52 t ha^{-1}) in comparison to 50 and 100 kg N ha^{-1}. Bulb yield of garlic increased with increased rate of nitrogen application up to 150 kg N ha^{-1} (6.97 t ha^{-1}) (Zaman *et al.*, 2011; ElHifny, 2010) reported the highest yield was attained in garlic plants treated with 120 kg N ha^{-1}.

Table 19. Interaction effect of cultivar and nitrogen fertilizer on total bulb yield of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum District during 2014/15

	Total bulb yield (t ha^{-1})			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	8.631^{ijk}	9.207$^{g\text{-}j}$	9.068^{hij}	10.690^{def}
Tsedey (G-493)	8.423^{ijk}	8.943^{hij}	9.217^{ghi}	11.727$^{a\text{-}d}$
Kuriftu	7.143^{mln}	7.542^{klm}	8.021$^{j\text{-}m}$	10.039^{fgh}
Felegdaero	8.259$^{i\text{-}l}$	10.353^{efg}	10.735^{def}	11.011$^{c\text{-}f}$
Bora-1	10.019^{fgh}	11.939^{abc}	12.606^{a}	12.278^{ab}
Bora-2	8.433^{ijk}	9.028^{hij}	9.167$^{g\text{-}j}$	11.231$^{a\text{-}d}$
Guahgot local	5.313^{o}	6.007^{no}	6.994^{mn}	7.213^{ml}
Mean		9.259		
S.E. (±)		0.721		
LSD (0.05)		1.186		
CV (%)		7.792		

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

4.4.5. Marketable Yield and Unmarketable Yield (t ha^{-1})

Analysis of variance showed that the interaction effect of cultivar and nitrogen fertilizer were high significant difference on marketable bulb yield. However, unmarketable bulb yield was not significantly influenced by either cultivars or nitrogen fertilizer rates (Appendix Table-2). Significant differences were observed by only the cultivar or nitrogen fertilizer for the marketable bulb yield. The highest marketable yield was recorded by cultivar Bora-1 (11.92 t ha^{-1}) at 82 kg ha^{-1} nitrogen fertilizer application but statistically non-significant at 123 kg N ha^{-1}. In addition, it was significantly higher than the other cultivars at all rates of nitrogen fertilizer. But across all cultivars, the marketable yield increased significantly with increasing rates of nitrogen fertilizer from 0 to 123 kg ha^{-1}. The other combination means were statistically significant and found in medium categories of the higher and the lower marketable yields per hectare.

However, the lowest marketable yield was recorded from cultivar Guahgot local which was produced 4.97 t ha^{-1} at zero nitrogen fertilizer application. When compared to Bora-1 at 82 kg ha^{-1} nitrogen application of preeminent harvest of marketable yield, gave greater harvest than Kuriftu, Bishoftu Nech, Bora-2, Tsedey and cultivar Felegdaero by 33.72%, 31.71%, 29.94%, 24.58% and 22.73% yield surplus respectively (Table 20). The present finding is supported by many researchers (Maryam *et al*, 2012; Kakar *et al*., 2002; Kumar and Rao, 1992) who indicated that higher marketable yield of garlic due to application of nitrogen was attributed to significantly higher bulb yield and quality. According to Tadese, 2009 investigation of the average marketable bulb yield per hectare indicated that garlic varieties differed significantly in producing total bulb yield.

Table 20. Interaction effect of cultivar and nitrogen fertilizer on marketable yield of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum District during 2014/15

Cultivars	Marketable yield (t/ha)			
	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	6.52 ^{hij}	8.23 $^{d-h}$	8.14 $^{g-j}$	9.60 $^{b-e}$
Tsedey (G-493)	5.79 $^{j-m}$	7.28 $^{g-j}$	8.99 $^{e-i}$	9.41 ^{bc}
Felegdaero	7.65 $^{h-k}$	9.43 $^{b-f}$	9.21 ^{bcd}	10.44 ^{bcd}
Kuriftu	5.51 $^{j-m}$	7.85 $^{j-m}$	7.90 ^{hij}	9.560 $^{c-h}$
Bora-1	8.15 $^{c-g}$	9.46 ^{bc}	11.92 ^{a}	11.88 ^{ab}
Bora-2	7.21 $^{f-i}$	8.52 $^{i-l}$	8.47 $^{f-j}$	10.68 ^{abc}
Guahgot local	4.97 ^{n}	5.33 ^{mn}	6.64 ^{klm}	6.50 ^{mln}
Mean	8.380			
S.E. (±)	1.210			
LSD (0.05)	2.430			
CV (%)	17.10			

Means represented with same letter(s) in columns and rows are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

4.5. Number and Size Distribution of Bulbs and Cloves

4.5.1. Marketable and Unmarketable Bulb Categories

The percentages of marketable and unmarketable bulbs were categorized in to small, medium, large and very large bulb sizes but these categories were not significantly influenced by the interaction effects of cultivar and nitrogen fertilizer rates. Marketable and unmarketable bulbs out of the middle 45 bulbs harvested in the middle rows were significantly influenced by separate effect of variety and nitrogen fertilizer. There were significant differences among varieties in medium, large and total marketable bulb categories while small and total bulb categories were significantly different in the proportion of unmarketable bulbs. The percentage of large size marketable bulbs was significantly influenced only by cultivar (Appendix Table 2).

Bora-1 had significantly the highest proportion of total marketable bulbs (93.33%), large (20%) and medium (44.44%) size bulbs. Tsedey (G-493) also had highest proportion of large size bulbs (20%) as equal as Bora-1. Guahgot local had significantly smallest proportion of total marketable (84.44%), large (13.33%) and medium (35.56%) size bulbs lower than the overall mean values. Significantly highest proportion of total number of marketable bulbs (93.33%) were obtained from the application 82 and 123 kg N ha^{-1} while lowest proportion was obtained from plots that did not receive fertilizer (82.22%). The proportion of large sized bulbs was equal for all rates of nitrogen fertilizer application except significantly lowest proportion was calculated for plots that did not receive fertilizer. Plots received 41 and 82 kg N ha^{-1} had equal proportion of medium size marketable bulbs while bulbs produced in plots that received 123 kg N ha^{-1} and did not receive fertilizer had highest (42.22%) and lowest (35.56%) proportion of medium size marketable bulbs, respectively (Table 20).

Varieties have their own genetic potential to produced quality and marketable bulb size. This is in line with Dickerson and Wall, 1993 who reported that nine cultivars of garlic had showed high genetically significant differences in their marketable bulb performances. Highly significant differences were recorded between the varieties in respect of weight of tuber size categories of small and large sized tuber on potato (Assefa, 2005). The differences among cultivars for marketable bulbs sizes is important for identifying the best cultivar which leads to easily adaptable, marketed and satisfy consumers preferences. This suggestion may be supported by Singh et al. (2012) that wide range of variability was recorded for marketable yield, these high ranges of variation among different lines could be utilized by breeders for the improvement of desired traits. Highly significant difference in marketable bulb yield was observed due to increase in the application of nitrogen, Increasing N application from 0 to 123 kg ha^{-1} increased marketable bulb yield of medium categories from 35.6 to 42.20 % however decreasing the total unmarketable bulb yield from 15.6 to 2.2 %.

Significant difference in unmarketable bulb yield was observed among the seven garlic cultivars only under total and small bulb category. Similarly, the unmarketable bulb yield was not significantly ($p > 0.05$) affected by cultivars and N fertilizer under very small, medium and large bulb categories of unmarketable bulbs. Besides, the variety and nitrogen interaction effects were also statistically non-significant ($p > 0.05$). This result seemed to suggest that unmarketable bulb yield might be controlled more effectively by genotype and nitrogen levels. The unmarketable bulb yield was significantly higher under small size categories by cultivar Guahgot local which exhibited 13.33% of small unmarketable bulbs. However the rest cultivars were not significantly differ from one to the other. In addition, nitrogen fertilizer rate was significantly influences the unmarketable bulbs under small categories. Maximum percentage of small unmarketable yield was recorded at zero rates of N application. As compared to improved varieties with farmers cultivars except Guahgot local, the proportion of yield wastage was high by improved varieties from 6.67-8.89 % but yield wastage of farmers' cultivar were ranges from 2.22-6.67 % under both small and total bulb categories. This might be farmers cultivar had showed well adapted to micro climatic conditions than improved varieties. Again as nitrogen fertilizer increased from 0-82 k N ha^{-1} the proportion of small unmarketable bulb size was decreased from 15.6-2.2 %. In contrast to the present finding, Tibebu *et al.,* 2014 unmarketable yield revealed no significant differences among varieties and similarly nitrogen fertilizer also had no significant effect on unmarketable yield.

Table 21. Effect of cultivar and nitrogen fertilizer on the total number, medium and large size of marketable and unmarketable bulbs of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Source of variation	Percentage of marketable bulb number out of 45 samples						Percentage of unmarketable bulb number out of 45 samples			
	Medium(5-6.35 cm)		Large (6.35-7.62 cm)		Total		Small (<5cm)		Total	
Cultivar	No.	%	No.	%	No.	%	No.	%	No.	%
Bishoftu Nech (W-14)	18.77^{ab}	42.22^{ab}	7.59^{abc}	17.78^{abc}	40.61^{ab}	91.11^{ab}	2.58^{b}	6.67^{b}	2.86^{b}	6.67^{b}
Tsedey (G-493)	16.75^{bc}	37.78^{bc}	7.28^{abc}	15.56^{abc}	39.83^{b}	88.89^{b}	3.94^{b}	8.89^{b}	4.09^{b}	8.89^{b}
Felegdaero	18.01^{abc}	40.00^{abc}	8.61^{ab}	20.00^{ab}	41.17^{ab}	91.11^{ab}	2.58^{b}	6.67^{b}	2.58^{b}	6.67^{b}
Kuriftu	18.52^{abc}	42.22^{abc}	6.51^{bc}	15.56^{bc}	39.89^{b}	88.89^{b}	2.71^{b}	6.67^{b}	2.97^{b}	6.67^{b}
Bora-1	19.62^{a}	44.44^{a}	9.45^{a}	20.00^{a}	42.31^{a}	93.33^{a}	0.93^{b}	2.22^{b}	0.93^{b}	2.22^{b}
Bora-2	17.61^{abc}	40.00^{abc}	7.92^{abc}	17.78^{abc}	41.45^{ab}	91.11^{ab}	1.14^{b}	2.22^{b}	1.39^{b}	2.22^{b}
Guahgot local	16.26^{c}	35.56^{c}	6.12^{c}	13.33^{c}	37.54^{c}	84.44^{c}	6.25^{a}	13.33^{a}	6.27^{a}	13.33^{a}
Mean	17.93	39.85	7.64	16.98	40.40	89.78	2.88	6.700	3.01	6.700
S.E. (±)	1.06	5.910	1.03	5.710	1.00	2.740	1.67	1.820	1.66	4.040
LSD (0.05)	2.130*	4.810*	2.06*	4.640*	2.00**	5.470**	3.36*	3.630*	3.32*	8.050*
N levels kg ha^{-1}										
0	16.37^{b}	35.6^{b}	7.59	15.60	37.30^{c}	82.2^{c}	6.36	13.3^{a}	6.64^{a}	15.6^{a}
41	17.90^{ab}	40.0^{ab}	7.28	17.80	40.15^{b}	88.9^{b}	3.55	8.90^{b}	3.97^{b}	8.90^{b}
82	18.16^{a}	40.0^{a}	7.66	17.80	41.88^{a}	93.3^{a}	0.87	2.20^{c}	0.92^{c}	2.20^{c}
123	19.30^{a}	42.2^{a}	8.06	17.80	42.26^{a}	93.3^{a}	0.73	2.20^{c}	0.81^{c}	2.20^{c}
Mean	17.93	39.85	7.64	16.98	40.40	89.78	2.88	6.700	3.01	6.700
S.E. (±)	0.8	5.840	0.78	5.940	0.76	1.790	1.27	1.250	1.25	1.250
LSD (0.05)	1.61**	3.590**	1.56	3.650	1.51**	3.570**	2.54**	2.500**	2.5**	2.510**

Means represented with same letter(s) in column in each treatment and characters are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05.

4.5.2. Marketable and unmarketable Cloves Categories

The combined effect of variety and N rates on yield of various bulb sizes is presented in Table (21). Highly significant differences were recorded among the varieties in respect of the size categories of small, medium, large and total sized cloves under marketable category. However no significant difference among the varieties with regard to unmarketable clove category except small sized cloves of garlic. Bora-1 produced significantly higher proportion of clove size in weight 16.25 (44.9 %), 22.80 (62.7 %), 27.10 (74.6 %) and 33.70 (93.0%) of under very small, small, medium, and large marketable categories respectively. Whereas the reverse was true of small clove size category of unmarketable cloves that Bishoftu Nech, Tsedey and Felegdaero produced significantly zero proportion of small cloves. But Guahgot local was produced higher unmarketable small sized clove 4.79 (39 %); non-significance differences were recorded among the rest cultivar themselves. different clove sized might be appeared due the genetic potential of the cultivars this is agreed with the result of Kassahun, 2006 who observed that majority of the accessions (68 %) were grouped in medium and heavy weight category, which could be considered as marketable yield. Fikreyohannes, 2005 reported that there are no grade standards for garlic crop in Ethiopia. Nevertheless, from experience it can be argued that size category is more of specific attribute for cultivars. Tadese, 2009 also reported that the highest record for small clove (54.52 g/plot) was from G-161-2 and the lowest, 9.68 g/plot was in Tsedey 92. Then clove size was significantly affected by the variety.

There was a consistent increase in the production of marketable clove categories with increasing levels N fertilizers from 0-123 kg N ha^{-1} in all clove categories. Unmarketable clove categories were not showed a significance differences on N fertilizer application in all groups of cloves. The highest marketable cloves were recorded at 123 kg N ha^{-1} but non-significant result was obtained from small clove categories between 82 and 123 kg N ha^{-1}. There were linearly increased with proportion of clove weights in the marketable whereas decreased in small unmarketable clove categories up to certain level. The result in agreement with Assefa, 2005 who reported that there was a consistent increase in the production of medium and large-sized bulb categories with increasing levels of applied N fertilizers.

Table 22. Effect of cultivar and nitrogen fertilizer on weight of marketable and unmarketable clove categories of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

	Clove weight									
	Marketable								Unmarketable	
Cultivars	Very small		Small clove		Medium clove		Large clove		Small clove	
	(g)	%	(g)	%	(g)	%	(g)	%	(g)	%
Bishoftu Nech	34.0ab	20.2	44.7bc	26.5	48.9bc	29.0	40.8bcd	24.2	0.0b	0.0
Tsedey	34.4ab	22.1	44.5bc	28.6	42.7c	27.4	33.9cd	21.8	0.0b	0.0
Felegdaero	18.3b	10.1	36.3c	20.0	60.6b	33.4	66.0b	36.4	0.0b	0.0
Kuriftu	20.3b	15.1	35.3c	26.2	44.1c	32.7	35.0cd	26.0	0.3b	6.2
Bora-1	44.9a	16.3	62.7a	22.8	74.6a	27.1	93.0a	33.8	1.0b	27.2
Bora-2	38.4a	17.8	60.0ab	27.8	60.8b	28.1	56.7bc	26.3	0.5b	8.5
Guahgot local	21.2b	22.0	30.1c	31.3	29.5d	30.6	15.5d	16.1	4.8a	39.0
Mean	30.2	17.2	44.8	25.6	51.6	29.4	48.7	27.8	1.0	14.4
S.E. (±)	7.92		8.610		7.710		13.26		1.28	
LSD (0.05)	15.9**		17.3**		15.5**		26.6**		2.6**	
N levels kg/ha^{-1}										
0	21.1b	18.43	29.8b	26.03	37.1c	32.4	25.5c	22.27	1.00	0.87
41	22.7b	15.60	37.6b	25.84	42.2c	29.0	41.9bc	28.80	1.10	0.76
82	33ab	16.21	54.0a	26.52	58.5b	28.7	57.8ab	28.39	0.30	0.15
123	44.0a	18.30	57.0a	23.70	68.6a	28.5	69.5a	28.90	1.40	0.58
Mean	30.20	17.13	44.60	25.52	51.60	29.7	48.68	27.09	0.95	0.59
S.E. (±)	5.99		6.510		5.83		10.02		0.96	
LSD (0.05)	12.00*		13.0**		11.7**		20.1**		1.93	

Means represented with same letter(s) in column in each treatment and character are not significantly different each other. SE (±) = standard error, LSD (5%) = least significant difference at P<0.05.

4.6. Cost Benefit Analysis in Garlic Cultivars

Partial budget analysis was shown a significance differences by ranking the treatments in order to increasing of the total cost. The highest total bulb yields 10690, 11727, 11011, 10039, 12606, 11231and 7213 kg ha^{-1} were recorded from Bishoftu Nech, Tsedey (G-493), Felegdaero, Kuriftu, Bora-1, Bora-2 and Guahgot local all cultivars at 123 kg N ha^{-1} but Bora-1 at 82 kg N ha^{-1}, respectively (Table 25). Moreover, the highest adjusted marketable bulb yield was high when 123 kg N ha^{-1} was applied to all six cultivars except Bora-1 gave highest adjustable bulb yield at 82 kg N ha^{-1} (CIMMYT, 1988). Accordingly, Bora-1 had the highest net benefit of 477127.2 Birr at 82 kg N ha^{-1} fertilizer application. This was followed by Tsedey (G-493) and Felegdaero that exhibited net benefit of 436940.8 and 404720.8 Birr both at 123 kg N ha^{-1} fertilizer application.

The highest marginal rate of return were recorded from cultivars Felegdaero and Bora-1 which exhibited 148.24 and 135.84 both at application of 41 kg N ha^{-1} which followed by four cultivars viz. (Tsedey (G-493), Kuriftu, Bora -2 and Bishoftu Nech (W-14) gave highest marginal rate of return of 77.49, 67.80, 65.48 and 47.92 at application of 123 kg N ha^{-1} as compare to the control, respectively. While the lowest marginal rate of return recorded by Guahgot local which gave 58.90 at application of 82 kg N ha^{-1}. On the other hand, application of 82 kg N ha^{-1} recorded the highest marginal rate of return for Felegdaero cultivar as compared to all combination treatments. According to CIMMYT (1988), the minimum acceptable marginal rate of return should be between 50 % and 100 %. The current study indicated that the marginal rate of return was above 50 % for all treatment combination. Moreover, Felegdaero and Bora-1 at 41 kg N ha^{-1} fertilizer application gave the highest marginal rate of return percentage which exhibited 14823.98 and 13583.88%, respectively. The highest benefit to cost ratio were obtained from Bora-1 (5.29) and followed by Tsedey (4.81) at 82 and 123 kg N ha^{-1} respectively, but the lowest was by Guahgot local (1.69) with no N fertilizer. Therefore, that could be recommended for the study area.

Table 23. Interaction effect of cultivar and nitrogen fertilizer on the economic analysis of garlic yield at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivars	kg N ha^{-1}	Average Yield (kgha-1)	Adjusted yield (kg ha-1)	Gross Field Benefit (ETB)	Total cost (ETB)	Net benefit (ETB)	Marginal rate of Return	Marginal rate of return (%)	Benefit cost ratio
Bishoftu Nech (W-14)	0	8631	7767.9	388395	88880	299515	3.37	336.99	3.37
Bishoftu Nech (W-14)	41	9207	8286.3	414315	89511.4	324803.6	40.05	4005.16	3.63
Bishoftu Nech (W-14)	82	9068	8161.2	408060	90142.8	317917.2	14.57	1457.25	3.53
Bishoftu Nech (W-14)	123	10690	9621	481050	90774.2	390275.8	47.92	4791.51	4.30
Tsedey (G-493)	0	8423	7580.7	379035	88880	290155	3.26	326.46	3.26
Tsedey (G-493)	41	8943	8048.7	402435	89511.4	312923.6	36.06	3606.05	3.50
Tsedey (G-493)	82	9217	8295.3	414765	90142.8	324622.2	27.29	2729.43	3.60
Tsedey (G-493)	123	11727	10554.3	527715	90774.2	436940.8	77.49	7749.22	4.81
Felegdaero	0	8259	7433.1	371655	88880	282775	3.18	318.15	3.18
Felegdaero	41	10353	9317.7	465885	89511.4	376373.6	148.24	14823.98	4.20
Felegdaero	82	10735	9661.5	483075	90142.8	392932.2	87.23	8723.25	4.36
Felegdaero	123	11011	9909.9	495495	90774.2	404720.8	64.38	6437.85	4.46
Kuriftu	0	7143	6428.7	321435	88880	232555	2.62	261.65	2.62
Kuriftu	41	7542	6787.8	339390	89511.4	249878.6	27.44	2743.68	2.79
Kuriftu	82	8021	7218.9	360945	90142.8	270802.2	30.29	3028.76	3.00
Kuriftu	123	10039	9035.1	451755	90774.2	360980.8	67.80	6779.95	3.98

During experimental period the price of urea and DAP fertilizer was 15 and 16 ETB kg^{-1} and selling price of garlic at farm gate was 50 ETB.

Table 24. Cont.…

Cultivars	kg N ha^{-1}	Average Yield (kg ha^{-1})	Adjusted yield (kg ha-1)	Gross Field Benefit (ETB)	Total cost (ETB)	Net benefit (ETB)	Marginal rate of Return	Marginal rate of return (%)	Benefit cost ratio
Bora-1	0	10019	9017.1	450855	88880	361975	4.07	407.26	4.07
Bora-1	41	11939	10745.1	537255	89511.4	447743.6	135.84	13583.88	5.00
Bora-1	82	12606	11345.4	567270	90142.8	477127.2	91.19	9118.80	5.29
Bora-1	123	12270	11043	552150	90774.2	461375.8	52.48	5247.64	5.08
Bora-2	0	8432.7	7589.43	379471.5	88880	290591.5	3.27	326.95	3.27
Bora-2	41	9027.7	8124.93	406246.5	89511.4	316735.1	41.41	4140.58	3.54
Bora-2	82	9167.3	8250.57	412528.5	90142.8	322385.7	25.18	2517.75	3.58
Bora-2	123	11231	10107.9	505395	90774.2	414620.8	65.48	6547.85	4.57
Guahgot local	0	5313	4781.7	239085	88880	150205	1.69	169.00	1.69
Guahgot local	41	6007	5406.3	270315	89511.4	180803.6	48.46	4846.15	2.02
Guahgot local	82	6994	6294.6	314730	90142.8	224587.2	58.90	5890.26	2.49
Guahgot local	123	7213	6491.7	324585	90774.2	233810.8	44.14	4413.78	2.58

During experimental period the price of urea and DAP fertilizer was 15 and 16 ETB kg^{-1} and selling price of garlic at farm gate was 50 ETB

4.7. Correlation of Yield and Yield Related Traits

Total bulb yield had positive and highly significant correlations with plant height, number of leaf per plants, bulb diameter and width, bulb and clove weight as well as clove width and length. However, total bulb yield showed negative and highly significant correlation with leaf width. Total dry biomass yield was positively and significantly correlated with all yields and yield related traits except with days to 50 % emergence and clove characters such as weight, length and width. Marketable bulb yield also exhibited significant correlation with plant height, bulb diameter, bulb weight, clove length and width, biological yield and total bulb yield (t ha^{-1}) but negative and significant correlation with 75% physiological maturity, leaf width, bulb neck diameter and number of cloves per bulb. In contrast to this study Asgharipour, M. and Javad M., 2012 reported a significant correlation between numbers of cloves per bulb versus bulb weight and between bulb weights versus cloves weight was not found. Garlic marketable yield was significantly dependent on the number of cloves per bulb, and increasing the number of cloves per bulb and hence reducing cloves weight reduces garlic marketable yield.

On the other hand, unmarketable bulb yield had positive and significant correlation with leaf width, bulb neck diameter and biological yield but negative and significant correlation with plant height, clove length and total yield per hectare (appendix Table-11). In agreement with result of Kasssahun, 2006; Hector *et al.*, (2012); Nori *et al.*, (2012) reported strong and positive correlations of total and marketable bulb yield with biological yield per plant (0.455), bulb dry weight (0.198), and weight of clove (0.115), bulb length (0.11), and days to maturity (0.094), leaf diameter (0.046) and plant height (0.027).

The significant correlation of total dry biomass yield of garlic with plant height, days to 75% physiological maturity, leaf width, leaf number per plant, bulb diameter, bulb weight and clove weight was also reported Unmarketable yield of garlic was significantly and positively correlated with leaf width, bulb neck diameter, biological yield per plant and shoot dry weight but negatively correlated with clove length, marketable bulb yield and harvest index (Nori *et al.,* 2012; Singh, *et al.*, 2013).

Days to emergence had positive and significant association with leaf number per plant, bulb diameter, and bulb weight, number of cloves per bulb and clove length. But it had negative and significant correlation with leaf width and 75 % physiological plant maturity. Plant physiological maturity had highly significant and positive correlation with leaf length and width, bulb neck diameter, bulb diameter, bulb length and average bulb weight. However, it showed significant and negative correlation with harvest index as well as total soluble solids (ºBrix). Similar results were reported by, Kassahun (2006), Yudhvir and Ramesh, (2003), and Panse, et al., (2013). The phenology of garlic such as days to emergence and physiological maturity had strong correlation with plant height, leaf number, leaf diameter and leaf length but at phenotypic level and it was negatively correlated with all the characters except dry weight above ground at genotypic level.

It was observed significant and positive correlations among the garlic growth traits (plant height, leaf length, leaf number per plant and leaf width) except the correlation between plant height and leaf width was no significant and between plant height and number of un marketable bulbs was negative and significant correlation. Plant height had strong and positive correlation with bulb diameter, bulb length, bulb and clove weight, leaf length and leaf number per plant, clove length, clove width, total and marketable yield as well as total soluble solid while leaf length and width showed significant and positive correlations with number of days to 75% physiological maturity, leaf number per plant, bulb neck diameter and bulb length, bulb diameter and number cloves per bulb.

Marketable small size bulb had positive and significant correlation with plant height, bulb diameter, bulb length and bulb weight and while medium and large size bulbs showed significant and positive correlation with pant height, leaf width, leaf number per plant, bulb diameter and length, bulb weight, clove length and width, clove weight, biological yield and total yields but significantly negative correlation with leaf width.

Correlation among some growth and yield characteristics of garlic, the effect of nitrogen fertilizer rates indicated a significant positive correlation with plant height, leaf length, leaf number per plant, bulb diameter, bulb length, average of bulb weight, total bulb yield, biological bulb yield per plant, average shoot dry weight per plant and bulb dry matter per plant. As increased the level of N, growth performance of garlic plant is increased based on the above positively correlated parameters. While other parameters were non-significant correlation with treatments of nitrogen doses (Appendix Table 10).

The interaction effect of varieties and nitrogen fertilizer rates were showed a positive relationship with number of days to plant physiological maturity, leaf width and bulb length whereas it was showed a negative correlation with number of days to clove emergency, leaf number per plant, bulb diameter, average of bulb weight and number cloves per bulb. The interaction effect of varieties and N was showed that the garlic varieties correlated differently at different rates of N and varieties (Appendix Table 8-9).

5. SUMMARY AND CONCLUSION

Garlic (*Allium sativum* L.) is one of the oldest cultivated crops and widely used around the world for its characteristic essence as a seasoning or condiment. It is also one of the most important vegetable bulb crops produced in Ethiopia, which is used as spice and flavoring agent for foods and as medicinal plant. Improving the yield and product quality of garlic is paramount importance for enhancing the production and productivity of the crop. Garlic is one of the bulb crops produced and used as spice ingredients as well as medicinal action in Tigray Region, however, farmers are producing the crop from the available cultivars without or with very low rates of nitrogen fertilizer. The cultivars produced in the region were not evaluated in comparison to improved varieties to the response of nitrogen fertilizer application. Therefore, selections based on morphological and agronomical characteristics of varieties that respond to fertilizer rates are essential to produce high yield; adaptable and high market acceptance. Also appropriate nitrogen fertilizer rates are very significant factor to increase the productivity, bulb quality and marketability of garlic. In view of this, the current investigation was conducted to select and determine the effect of variety, nitrogen doses and their interaction on growth and yield of garlic at Guahgot Farmers Training Center (FTC), Gantaafeshum district of Tigray region, northern Ethiopia.

The experiment was conducted during 2014/2015 in Gantaafeshum district in Tigray region with objectives of assessing the effect of nitrogen rates on yield and yield related traits of garlic. Seven garlic cultivars (three improved, three introduced and one local) and four nitrogen fertilizer rates (0, 41, 82, 123 kg N ha^{-1}) were arranged as 7 x 4 factorial treatments and laid out as a randomized complete block design with three replications.

All yield and yield related traits were significantly influenced by the interaction of cultivar and nitrogen fertilizer except leaf length, leaf number per plant, bulb length and sizes of bulbs and cloves of different categories that were significantly influenced either by both cultivar and nitrogen or one of these. The highest total yield was obtained from the cultivar Bora 1 (12.61 t ha^{-1}) at the rate of 82 kg N ha^{-1} but the yield decreased to 12.27 t ha^{-1} as the nitrogen level increased to 123 kg N ha^{-1}. The lowest yield was recorded from the local cultivar Guahgot

(5.31 t ha^{-1}) without N fertilizer application. Bulb quality was determined based on number of marketable bulbs and weight of cloves where Bora 1 had 44.4 % and 20 % of bulbs categorized under medium and large categories, respectively. This cultivar had also the highest proportion of marketable cloves categorized under medium (27.10 %) and large (33.80 %) clove categories. The cost benefit analysis indicated that Felegdaero at 41kg N ha^{-1} followed by cultivar Bora-1at 41 kg N ha^{-1} rates had maximum marginal economic return of 148.24 and 135.84, respectively.

In general, it was observed that farmers' cultivars were not completely inferior as compare to released varieties either without or at different rates of nitrogen fertilizer application. These suggested that the importance of testing varieties and farmers cultivars for the response to different rates of nitrogen fertilizer application. Therefor a greater attention should be given for the investigation of these cultivars at similar climatic conditions and nitrogen rates on their yield and quality stability to recognize as formal varieties in the national level. Small scale farmers at Gantaafeshum district and similar agro-ecology areas would use these packages for growing garlic for better yield. However, it is hardly possible to make this as final recommendation because it was the one growing season research result and for one site in the district. As conclusion, it is suggested to repeat the experiment once again in the study area to release the final packages.

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7. APPENDIXES

Appendix Table 1. Mean squares from analysis of variance (ANOVA) for phenology, growth, yield and yield components of seven garlic cultivars evaluated during 2014/15

Trait	Replication (2)	Variety (A) (6)	Nitrogen (B) (3)	A x B (27)	Error (54)	CV (%)	Mean
NDE	2.17	31.13**	11.79	7.14**	4.63	16.46	13.07
NDPM	23.99	136.52**	39.26	54.39**	35.61	3.93	151.68
PH (cm)	120.34	107.23**	153.22**	46.17*	32.39	8.02	70.95
LL (cm)	26.42	38.91	122.50**	24.83	20.2	8.77	51.23
LW (cm)	0.05	0.75**	0.16	0.20**	0.12	15.13	2.27
LNP	2.32	2.98	1.40*	1.67	1.39	9.24	12.74
SDWP (g)	0.12	6.58**	5.20*	1.24*	1.41	29.33	4.05
BND (cm)	0.43	0.08**	0.13	0.10**	0.05	17.9	1.26
BD (cm)	1.06	4.04**	1.06**	0.84**	0.43	13.16	5
BL (cm)	0.22	0.53**	1.55**	0.20*	0.17	7.7	5.4
BW (g)	152.69	273.41**	200.52**	64.17*	43.08	19.24	34.11
BDWP (g)	203.99	85.66**	56.75**	3.59*	7.33	30.56	8.86
NCB	16.62	109.40**	26.29*	20.59**	9.97	16.39	19.27
CW (g)	0.99	1.13**	0.17	0.55**	0.29	15.87	3.4
Cwid (cm)	0.18	0.40**	0.12**	0.19**	0.11	16.61	1.96
Cle (cm)	0.17	1.58**	0.17	0.54**	0.29	14.83	3.65
TY (t/ha)	53.1	192.77**	402.80**	41.12**	18.673	14.76	9.259
DBYP (g)	114.92	111.54**	589.89**	33.48**	52.33	17.35	41.69
HI (%)	96.5	429.82**	124.96	148.91*	100.51	23.92	41.91

The * and **, significant at P<0.05 and P<0.01, respectively. Numbers in parenthesis represents degrees of freedom, A x B = interaction of factor cultivar (A) and factor Nitrogen fertilizer (B), and CV (%) = coefficient of variation in percent. NDE-Number of days to emergency, NDPM-number of days to 75% physiological maturity, PH- plant height, LL-leaf length, LW-leaf width, LNP-leaf number per plant, SDWP- shoot dry weight per plant, BND-bulb neck diameter, BD-bulb diameter, BL-bulb length, BW-bulb weight, BDWP-bulb dry weight per plant, NCB-number of cloves per bulb, CW-clove weight, Cwid-clove width, Cle-clove length, TY-total yield, DBYP-dry biological yield per plant and HI-harvest index.

Appendix Table 2. Mean squares from analysis of variance (ANOVA) for marketable and unmarketable clove categories of seven garlic cultivars evaluated during 2014/15

Trait	Replication (2)	Variety (A) (6)	Nitrogen (B) (3)	A x B (27)	Error (54)	Means
Number of Unmarketable bulbs						
Small	110.98	39.06*	148.24**	7.98	16.81	2.88
Medium	0.68	0.2	0.23	0.25	0.21	0.14
Large	0	0	0	0	0	0
Very Large	0	0	0	0	0	0
Total	104.75	37.93*	159.75**	6.65	16.45	3.01
Number of marketable bulbs						
Small	60.43	9.5	16.94	9.9	11.87	14.79
Medium	148.07	16.41*	30.43**	4.04	6.79	17.93
Large	5.27	15.94*	11.43	6.63	6.33	7.64
Very Large	0.107	0.107	0.107	0.107	0.107	0.036
Total	23.51	28.26**	107.15**	2.28	5.99	40.4
Unmarketable Clove Weight (g)						
Very Small Clove	276.95	89.42	53.35	75.79	67.52	5.55
Small Clove	8.74	36.92**	4.85	7.35	9.76	0.95
Medium Clove	0.63	0.84	0.53	0.5	0.61	0.14
Large Clove	0	0	0	0	0	0
Total	254.77	151.39	58.79	90.03	91.96	6.6
Marketable Clove Weight (g)						
Very Small Clove	487	1271.9**	2365.9**	371.9	376.5	30.2
Small Clove	1116.4	1860.00**	3733.20**	359.9	444.4	44.8
Medium Clove	491.4	2656.80**	4426.20**	324.5	356.3	51.6
Large Clove	3638	7797	7713	307	1055	48.7
Total	11430	40022**	68204**	2416	4889	175

The * and **, significant at P<0.05 and P<0.01, respectively. Numbers in parenthesis represents degrees of freedom, A x B = interaction of factor cultivar (A) and factor Nitrogen fertilizer (B), and CV (%) = coefficient of variation in percent.

Appendix Table 3. Effect of cultivar on phenology of seven garlic cultivars at Guahgot (FTC) in Ganta'afeshum district during 2014/15

Cultivar	Days to 50% emergence	Days to 75% physiological maturity	Bulb neck diameter (cm)	Leaf width (cm)	Clove weight (g)	Clove length (cm)	HI (%)
Bishoftu Nech	14.08^{ab}	150.73b	1.31^{b}	2.23^{b}	3.41^{a-d}	3.82^{a}	43.327^{ab}
Tsedey	15.55^{a}	151.73b	1.31^{b}	2.21^{b}	3.27^{bcd}	3.70^{a}	37.819^{bc}
Felegdaero	12.43^{b}	148.26b	1.17^{b}	2.01^{b}	3.73^{ab}	3.72^{a}	48.626^{a}
Kuriftu	12.81^{b}	149.77b	1.14^{b}	2.14^{b}	3.09^{cd}	3.59^{a}	44.417^{ab}
Bora-1	12.43^{b}	150.97b	1.17^{b}	2.25^{b}	3.83^{a}	3.96^{a}	44.514^{ab}
Bora-2	13.65^{b}	151.64^{b}	1.18^{b}	2.28^{b}	3.48^{abc}	3.88^{a}	44.386^{ab}
Guahgot local	10.55^{c}	158.67^{a}	1.53a	2.80^{a}	2.97^{d}	2.87^{b}	30.308^{c}
Mean	13.07	151.68	1.26	2.27	3.40	3.65	41.91
S.E. (±)	2.15	5.970	0.23	0.34	0.54	0.54	10.03
LSD (0.05)	1.803	4.863	0.185	0.282	0.435	0.437	4.50
CV (%)	16.46	3.930	17.90	15.30	15.87	14.83	23.92

Means represented with same letter(s) in a column in each trait are not significantly different each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Appendix Table 4. Effect of cultivar and nitrogen fertilizer on growth, yield and yield components of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Plant height (cm)	Shoot dry weight per plant	Bulb diameter (cm)	Bulb length (cm)	Bulb weight (g)
Bishoftu Nech (W-14)	72.33 ^{ab}	4.34 ^{b}	5.38 ^{a}	5.50 ^{ab}	37.79 ^{a}
Tsedey (G-493)	71.45 ^{ab}	4.27 ^{b}	5.27 ^{b}	5.40 ^{abc}	35.46 ^{ab}
Felegdaero	69.20 ^{bc}	3.15 ^{c}	5.46 ^{a}	5.10 c	38.98 ^{a}
Kuriftu	69.64 ^{bc}	3.29 ^{c}	4.85 ^{b}	5.23 ^{bc}	31.76 ^{b}
Bora-1	75.24 a	3.88 ^{bc}	5.42 ^{a}	5.63 ^{a}	38.26 ^{a}
Bora-2	72.47 ^{ab}	3.95 ^{bc}	4.86 ^{b}	5.35 ^{abc}	31.52 ^{b}
Guahgot local	66.35 ^{c}	5.08 ^{a}	3.79 ^{b}	5.59 ^{ab}	25.52 ^{c}
Mean	70.95	3.99	5.00	5.400	34.11
S.E. (±)	5.69	0.91	0.66	0.420	6.56
LSD (0.05)	4.962	0.81	0.551	0.389	5.715
CV (%)	8.60	24.9	13.50	8.800	20.60
kg N ha^{-1}					
0	68.356 ^{b}	3.54 b	4.7048 ^{b}	5.1063 ^{c}	29.685 ^{c}
41	70.869 ^{b}	4.10 ^{ab}	5.0333 ^{ab}	5.3274 ^{bc}	34.661 ^{ab}
82	70.197 ^{b}	3.92 ^{ab}	4.9464 ^{ab}	5.4487 ^{b}	33.870 ^{b}
123	74.393 ^{a}	4.65 a	5.3333 a	5.7201 ^{a}	38.233 ^{a}
Mean	70.95	3.99	5.00	5.40	34.11
S.E. (±)	5.690	0.91	0.66	0.42	6.56
LSD (0.05)	3.795	0.667	0.518	0.275	4.791
CV (%)	8.700	27.2	16.9	8.30	22.9

Means represented with same letter(s) in a column in each trait are not significantly different each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Appendix Table 5. Effect of cultivar and nitrogen fertilizer on growth, yield and yield components of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum district during 2014/15

Cultivar	Bulb dry weight per plant (g)	Number of cloves per bulb	Clove diameter (cm)	Total yield (t/ha)	Biological yield per plant (g)
Bishoftu Nech (W-14)	8.410 ^{cd}	23.50 ^{a}	1.94 $^{a-d}$	9.88 ^{b}	12.75 ^{b}
Tsedey (G-493)	9.343 ^{c}	22.99 ^{a}	1.89 ^{bcd}	8.57 ^{c}	13.62 ^{b}
Felegdaero	13.645 a	17.38 c	2.15 ^{ab}	10.41^{ab}	16.79 ^{a}
Kuriftu	7.558 ^{de}	20.14 ^{b}	1.78 ^{cd}	8.37 ^{c}	10.85 ^{c}
Bora-1	11.848 ^{b}	16.21 ^{c}	2.19 ^{a}	11.18 ^{a}	15.73 ^{a}
Bora-2	7.093 ^{e}	17.08 ^{c}	2.05 ^{abc}	9.27 ^{bc}	11.04 ^{c}
Guahgot local	5.493 ^{f}	17.60 ^{bc}	1.69 ^{d}	7.12 ^{d}	10.58 ^{c}
Mean	9.08	19.27	1.96	9.260	13.05
S.E. (±)	1.44	3.16	0.32	1.370	1.700
LSD (0.05)	1.918	2.651	0.265	1.500	2.258
CV (%)	15.89	16.90	16.61	14.76	13.01
kg N ha^{-1}					
0	6.54 ^{d}	18.2803 ^{b}	1.83 ^{b}	7.44 ^{d}	9.98 ^{c}
41	8.32 ^{c}	18.9921 ^{ab}	2.00 ^{b}	8.86 ^{c}	12.44 ^{b}
82	9.54 ^{b}	19.2311 ^{ab}	1.96 ^{b}	9.76 ^{b}	13.39 ^{b}
123	11.82 ^{a}	20.5797 ^{a}	2.04 ^{a}	10.98 ^{a}	16.38 ^{a}
Mean	9.08	19.27	1.96	9.260	13.05
S.E. (±)	1.44	3.16	0.32	1.370	3.660
LSD (0.05)	1.821	2.579	0.220	1.100	2.720
CV (%)	15.89	16.39	16.61	19.30	20.80

Means represented with same letter(s) in a column in each trait are not significantly different each other. SE = standard error, LSD (5%) = least significant difference at P<0.05 and CV (%) = coefficient of variation.

Appendix Table 6. Correlation of treatments with growth and yield parameters of garlic

	NDE	NDPM	PH (cm)	LL (cm)	LW (cm)	LNP	BND(cm)	BD(cm)	BL(cm)	BW (g)
Var.	0.403^{**}	0.291^{**}	0.107^{ns}	0.007^{ns}	0.371^{**}	-0.326^{**}	0.111^{ns}	-0.468^{**}	0.105^{ns}	-0.403^{**}
N	0.118^{ns}	0.297^{ns}	0.337^{**}	0.337^{**}	0.095^{ns}	0.332^{**}	0.064^{ns}	0.234^{*}	0.447^{**}	0.334^{**}
Var. * N	-0.488^{**}	0.490^{**}	-0.029^{ns}	0.102^{ns}	0.401^{**}	-0.340^{**}	0.155^{ns}	-0.467^{**}	0.294^{**}	-0.359^{**}

The * and **, significant at P<0.05 and P<0.01, respectively. NDE-number of days to 50% emergency, NDPM-number to 75% physiological maturity, PH-plant height, LL-leaf length, LW-leaf width, LNP-leaf number per plant, BND-bulb neck diameter, BD-bulb diameter, BL-bulb length, BW-bulb weight.

Appendix Table 7. Correlation of treatments with growth and yield parameters of garlic

	NCB	CW (g)	CD (cm)	CLe (cm)	Y(t/ha)	BYP (g)	SDWP (g)	DBW (g)	TBY (t/ha)	HI (%)
Var.	-0.525^{**}	-0.095^{ns}	-0.077^{ns}	-0.265^{*}	-0.200^{ns}	0.045^{**}	0.146^{ns}	-0.261^{*}	0.020^{ns}	-0.193^{ns}
N	0.191^{ns}	0.146^{ns}	0.186^{ns}	0.112^{ns}	0.590^{**}	0.619^{**}	0.308^{**}	0.462^{**}	0.548^{**}	0.015^{ns}
Var.*N	-0.655^{**}	0.085^{ns}	0.107^{ns}	-0.179^{ns}	-0.192^{ns}	0.080^{ns}	0.151^{ns}	-0.171^{ns}	0.037^{ns}	-0.190^{ns}

* designated significant at P<0.05, ** indicate significant at P<0.01 LSD tests and NS= indicate non-significant results**.** NCB-number of cloves per bulb, CW-clove weight, CD-clove diameter, CLe-clove length, Y-bulb yield, BYP- biological yield per plant, SDWP-shoot dry weight per plant, DBW-dry bulb weight, TBY-Total biological bulb yield per hectare, HI-harvest index, TSS- total soluble solid

Appendix Table 6. Yield correlations with growth and yield components parameters

PARAMETERS	NDE	NDPM	PH(cm)	LL(cm)	LW(cm)	LNP	BND(cm)	BD(cm)	BL(cm)	BW(g)	NCB	CW	Cwid
NDE	1.000												
NDPM	-0.196 ns	1.000											
PH (cm)	0.182 ns	0.187 ns	1.000										
LL(cm)	0.145 ns	0.350**	0.553**	1.000									
LW(cm)	-0.286**	0.556**	0.110 ns	0.413**	1.000								
LNP	0.259*	-0.130 ns	0.291 **	0.374**	-0.095 ns	1.000							
BND (cm)	-0.162 ns	0.432**	-0.043 ns	0.268*	0.524**	-0.015 ns	1.000						
BD(cm)	0.375**	-0.454**	0.413**	0.108 ns	-0.479**	0.475**	-0.304**	1.000					
BL(cm)	-0.005 ns	0.487**	0.461**	0.618**	0.529**	0.329**	0.379**	0.095 ns	1.000				
BW(g)	0.284**	-0.257*	0.564**	0.241*	-0.260*	0.506**	-0.163 ns	0.914**	0.311**	1.000			
NCB	0.531**	-0.124 ns	0.145 ns	0.245*	-0.058 ns	0.421**	0.187 ns	0.237*	0.149 ns	0.242*	1.000		
CW	-0.161 ns	-0.037 ns	0.318**	0.073 ns	-0.096 ns	0.167 ns	-0.115 ns	0.587 **	0.185 ns	0.655 **	-0.354 **	1.000	
Cwid	-0.177 ns	-0.104 ns	0.234 *	-0.083 ns	-0.154 ns	-0.055 ns	-0.247 ns	0.459 **	0.018 ns	0.443 **	-0.424 **	0.814 **	1.000
CLe (cm)	0.276*	-0.172 ns	0.548 **	-0.056 ns	-0.414 **	0.118 ns	-0.426**	0.688**	0.078 ns	0.699 **	0.010 ns	0.575**	0.562 **
Y (t/ha)	0.208 ns	-0.205 ns	0.520 **	0.209 ns	-0.305 **	0.456 **	-0.210 ns	0.773 **	0.270 *	0.799 **	0.086 ns	0.562 **	0.495 **
BYP(g)	0.103 ns	0.293 **	0.428 **	0.685 **	0.398 **	0.420 **	0.449 **	0.244 *	0.672 **	0.372 **	0.313**	0.133 ns	-0.004 ns
SDWP(g)	0.047 ns	0.523 **	0.304 **	0.643 **	0.621**	0.234*	0.466 **	-0.145 ns	0.666 **	0.009 ns	0.273 *	-0.121 ns	-0.219 *
BDMP(g)	0.081 ns	-0.192 ns	0.266 *	0.138 ns	-0.289 **	0.361**	0.014 ns	0.609 **	0.157 ns	0.648 **	0.084 ns	0.486 **	0.362 **
TBYH(t/ha)	0.107 ns	0.285 **	0.461**	0.684 **	0.392 **	0.442 **	0.436 **	0.294 **	0.669 **	0.440 **	0.330 **	0.181 ns	0.017 ns
HI (%)	0.029 ns	-0.511**	-0.151 ns	-0.503 **	-0.689 **	-0.072 ns	-0.565**	0.270 *	-0.470 **	0.114 ns	-0.246 *	0.185 ns	0.328 **
TSS (^{o}Brix) (%)	0.388 **	-0.263 *	0.231*	0.026 ns	-0.419 **	0.273*	-0.162 ns	0.603 *	-0.103 ns	0.498 **	0.190 ns	0.337 **	0.276 *

* designated significant at P<0.05, ** indicate significant at P<0.01 LSD tests and NS= indicate non-significant results.

Cont… of Appendix table 8

PARAMETERS	CLe(cm)	Y(t/ha)	BYP (g)	AGDBYP (g)	DMBY (g)	TBYH (t/ha)	HI (%)	TSS (^{o}Brix) (%)
CLe(cm)	1.000							
Y(t/ha)	0.607 **	1.000						
BYP(g)	-0.044 ns	0.430**	1.000					
SDWP (g)	-0.204 ns	-0.008 ns	0.724**	1.000				
BDMP(g)	0.321**	0.708**	0.432**	-0.098 ns	1.000			
TBYH(t/ha)	0.000 ns	0.421**	0.958**	0.720**	0.444**	1.000		
HI (%)	0.352 **	0.350**	-0.538**	-0.720**	0.121 ns	-0.617**	1.000	
TSS (^{o}Brix) (%)	0.461**	0.488**	0.086 ns	-0.211 ns	0.492**	0.098 ns	0.263 *	1.000

* designated significant at P<0.05, ** indicate significant at P<0.01 LSD tests and NS= indicate non-significant results.

Appendix Table 9. Correlations with bulb and clove size categories

PARAMETERS	NUMBY			NMBY	NMBY	NMBY	UMBY	BW (g)	NCB	CW (g)	Y (t/ha)	UMCW
	S (<5cm)	M (5-6.35 cm)	Total	S (<5cm)	M (5-6.35cm)	L (6.35-7.62cm)	S (<5cm)					VSC (g)
NUMBY S	1.000											
NUMBY M	-0.122 ns	1.000										
NUMBY Total	0.995 **	-0.023 ns	1.000									
NMBY S	0.048 ns	-0.261 *	0.022 ns	1.000								
NMBY M	-0.669 **	0.140 ns	-0.660 **	-0.578 *	1.000							
NMBY L	-0.354 **	0.042 ns	-0.352 **	-0.574 **	0.253 *	1.000						
UMBY S	-0.920 **	-0.069 ns	-0.934 **	0.021 ns	0.582 **	0.469 **	1.000					
BW (g)	-0.132 ns	-0.118 ns	-0.145 *	-0.011 ns	0.078 ns	0.225 *	0.252 *	1.000				
NCB	-0.121 ns	-0.023 ns	-0.124 ns	0.047 ns	0.029 ns	0.017 ns	0.107 ns	0.242 *	1.000			
CW (g)	0.106 ns	-0.174 ns	0.089 ns	0.098 ns	-0.120 ns	0.074 ns	0.0474 ns	0.655 **	-0.354 **	1.000		
Y (t/ha)	-0.325 **	-0.196 ns	-0.347 **	0.026 ns	0.206 ns	0.293 **	0.474 **	0.799 **	0.086 ns	0.562 **	1.000	
DMBW (g)	-0.147 ns	-0.173 ns	-0.165 ns	0.023 ns	0.046 ns	0.265 *	0.305 **	0.648 **	0.084 ns	0.488 **	0.708 **	
UMCW VSC (g)	0.219 *	0.070 ns	0.228 *	0.012 ns	-0.256 *	0.049 ns	-0.202 ns	0.077 ns	0.099 ns	0.145 ns	-0.053 ns	1.000
UMCW SC (g)	0.178 ns	-0.075 ns	0.172 ns	0.150 ns	-0.188 ns	-0.246 *	-0.233 *	-0.244 *	-0.092 ns	-0.110 ns	-0.232 *	0.184 ns
UMCW MC (g)	0.093 ns	-0.050 ns	0.089 ns	0.083 ns	-0.104 ns	-0.136 ns	-0.1289 ns	-0.182 ns	-0.161 ns	-0.040 ns	-0.174 ns	-0.013 ns
UMCW Total (g)	0.258 *	0.032 ns	0.264 *	0.067 ns	0.295 **	-0.050 ns	-0.264 *	-0.029 ns	0.044 ns	0.087 ns	-0.138 ns	0.935 **
MCW VSC (g)	-0.270 *	-0.073 ns	-0.280 *	-0.042 ns	0.176 ns	0.240 *	0.341 **	0.214 ns	0.227 *	0.044 ns	0.379 **	0.012 ns
MCW SC (g)	-0.414 **	-0.317 ns	-0.420 **	-0.102 ns	0.301 **	0.352 **	0.494 **	0.283 **	0.094 ns	0.163 ns	0.420 **	-0.037 ns
MCW MC (g)	-0.354 **	-0.031 ns	-0.360 **	-0.088 ns	0.216 *	0.440 **	0.501 **	0.440 **	0.004 ns	0.297 ns	0.613 **	-0.150 ns
MCW LC (g)	-0.312 **	-0.098 ns	-0.324 **	-0.030 ns	0.139 ns	0.454**	0.487 **	0.369 **	-0.086 ns	0.303 **	0.566 **	-0.138 ns
MCW Total (g)	-0.401 **	-0.076 ns	-0.411 **	-0.073 ns	0.239 *	0.460 **	0.552 **	0.400 **	0.043 ns	0.262 *	0.605 **	-0.105 ns
TSS (°Brix) in (% age)	-0.140 ns	0.020 ns	-0.139 ns	-0.026 ns	0.029 ns	0.314 **	0.272 *	0.425 **	0.179 ns	0.314 **	0.441 **	-0.025 ns

* designated significant at P<0.05, ** indicate significant at P<0.01 LSD tests and NS= indicate non-significant results.

Cont. Appendix Table 9

PARAMETERS	UMCW SC (g)	UMCW MC (g)	UMCW Total (g)	MCW VSC (g)	MCW SC (g)	MCW MC (g)	MCW LC (g)	MCW Total (g)	TSS (°Brix) in (% age)
UMCW SC (g)	1.000								
UMCW MC (g)	0.217 *	1.000							
UMCW Total (g)	0.512 *	0.139 ^{ns}	1.000						
MCW VSC (g)	-0.089 ^{ns}	-0.070 ^{ns}	-0.024 ^{ns}	1.000					
MCW SC (g)	-0.226 *	-0.081 ^{ns}	-0.114 ^{ns}	0.780 **	1.000				
MCW MC (g)	-0.290 **	-0.209 ^{ns}	-0.244 *	0.624 **	0.686 **	1.000			
MCW LC (g)	-0.295 **	-0.169 ^{ns}	-0.232 *	0.422 **	0.416 **	0.751	1.000		
MCW Total (g)	-0.284 **	-0.165 ^{ns}	-0.200 ^{ns}	0.789 **	0.810 **	0.916	0.835	1.000	
TSS (°Brix) in (% age)	-0.515 **	-0.324 **	-0.218 **	0.203 *	0.238 *	0.446 **	0.387	0.395 **	1.000

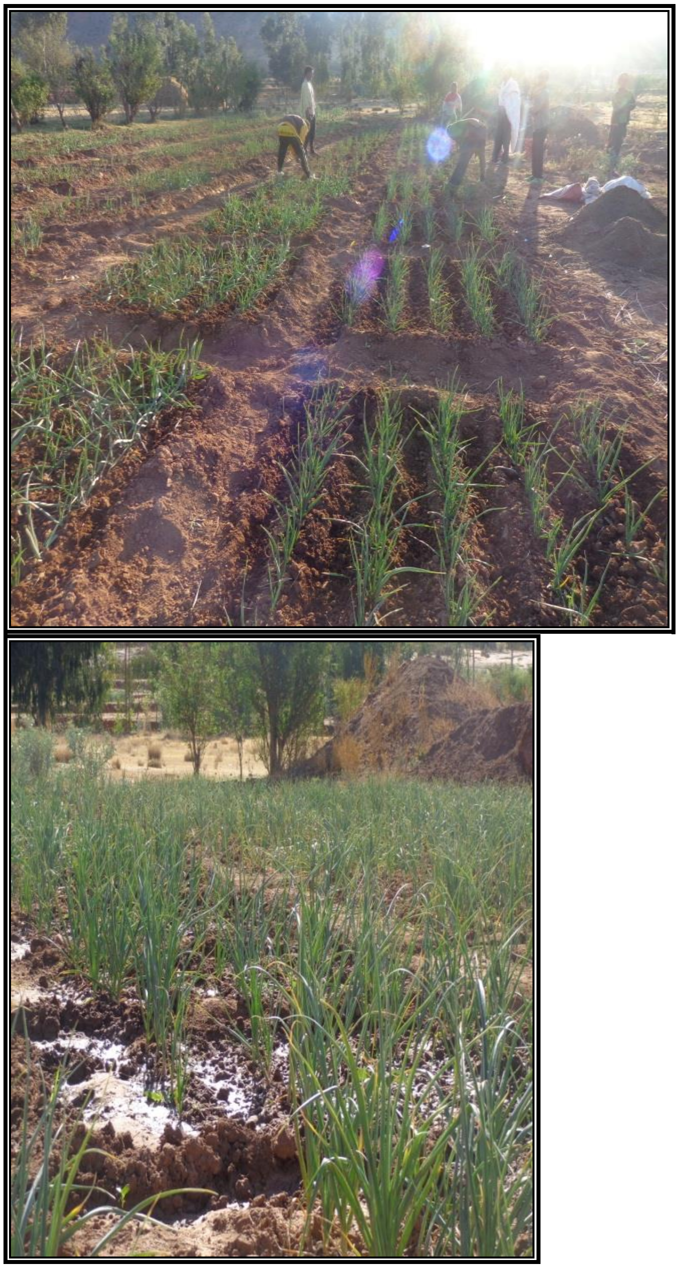
* designated significant at P<0.05, ** indicate significant at P<0.01 LSD tests and NS= indicate non-significant results.

Appendix Figure 1 Ploughing, land preparation and lay out

Appendix Figure 2 Clove preparation and planting

Appendix Figure 3 Watering using water pumps and clove germination


Appendix Figure 4 Farmers' evaluation on vegetative growth of garlic



Appendix Figure 5 Vegetative growth performance of garlic

Figures on data collection and GPS reading

Appendix Figure 6 Harvesting and data collection

Appendix Figure 7 Bulbs after harvest and laboratory measurements

Weight measurements using sensitive balance

Photo on laboratory measurements